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Spatial Distribution and Risk Assessment of Heavy Metals in Sediments of the Mangrove Ecosystem in Ras Mohammed Protectorate, Gulf of Aqaba, Red Sea

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ABSTRACT

Water systems worldwide serve as significant repositories for various contaminants, particularly heavy metals. Anthropogenic activities release heavy metals like lead and cadmium into water bodies, leading to bioaccumulation and biomagnification in aquatic organisms. The consumption of contaminated fish and shellfish poses health risks to humans, while heavy metal pollution disrupts aquatic ecosystems and biodiversity. Effective measures and regulations are crucial to mitigate heavy metal pollution, safeguard the environment, and protect human health. This study focused on the spatial distribution of heavy metals within the sedimentary deposits of the Mangrove ecosystem in Ras Mohammed, Gulf of Aqaba. The copper, iron, cadmium, lead, zinc, and manganese concentrations were analyzed, revealing varying levels across different sampling locations. While, most heavy metal concentrations were within acceptable thresholds, cadmium concentrations slightly exceeded the threshold level, potentially affecting environmental quality due to increased recreational activities. The geo-accumulation index indicated unpolluted to moderately polluted conditions. The metal pollution index showed elevated contamination in specific areas. The ecological risk assessment suggested low toxicity risks to aquatic life in the study region. Overall, this investigation provides insights into the heavy metal distribution and its potential implications in Ras Mohammed protectorate.

INTRODUCTION

On a global scale, various water systems, including rivers, lakes, estuaries, bays, and seas, act as significant repositories for a wide range of contaminants, notably heavy metals (**Ilie *et al.*, 2017; Younis *et al.*, 2022**). The release of heavy metals, such as lead, mercury, cadmium, and arsenic, into water bodies is primarily attributed to anthropogenic activities such as industrial processes, mining operations, and agricultural practices (**Younis, 2020; Taher *et al.*, 2023; Younis *et al.*, 2023)**. These toxic substances have the ability to accumulate in aquatic organisms, leading to bioaccumulation and biomagnification along the food chain. Consequently, the consumption of contaminated fish and shellfish can pose significant risks to human health, including the development of neurological disorders, organ damage, and even cancer. Furthermore, heavy metal pollution can disrupt the delicate balance of aquatic ecosystems, resulting in the decline of sensitive species and loss of biodiversity (**Younis *et al.*, 2019; Soliman *et al.*, 2020)**. Therefore, it is imperative to implement effective measures and regulations to mitigate heavy metal pollution, safeguard the environment, and protect human health.

Several researchers (**Haque *et al.*, 2004; Ilie, 2017; Hanafy *et al.*, 2021**) have conducted extensive studies on the topic of heavy metal contamination and its implications for public health. In 2017, trace metals were identified as having the potential to be transported and subsequently incorporated into sedimentary deposits. The influence of water bodies on heavy metal transportation and deposition is influenced by factors such as grain size and mineralogy (**Haque *et al.*, 2004**), resulting in enduring negative consequences. The persistent nature of certain metals in sediments (**Öğlü *et al.*, 2015)** contributes to their bioaccumulative potential and poses a significant risk to the aquatic environment, leading to pollution. It is worth noting that the presence of silt in water systems exacerbates these concerns.

Considering the substantial role of aquatic ecosystems as reservoirs for heavy metal accumulation, the contamination of sediments with these metals presents a significant and alarming hazard that warrants attention and remedial actions **(Younis *et al.*, 2019; El-Naggar *et al.*, 2021)**.

Mangroves, characterized as deciduous evergreen angiosperm trees, inhabit the wetlands and intertidal zones of tropical and subtropical regions within the latitudinal range of 25 degrees north and 25 degrees south. These trees are primarily found in estuaries, where freshwater and saltwater converge are found. Thriving in intertidal environments with alluvial soils rich in fine-grained particles and high moisture and salinity levels, mangroves undergo submergence during low tide and emergence during high tide. While, over 110 plant species are classified as mangroves, only a select few are officially recognized as true mangroves. Notable species include *Avicennia marina,* commonly known as Hara, Mangrove, or white or gray mangroves, and *Rhizophora mangle*, referred to as Red mangrove (**Elnaggar *et al.*, 2022**).

Hurghada represents the northernmost boundary of mangrove distribution along the Red Sea coast, encompassing a mangal vegetation area of approximately 525 hectares. This expanse stretches from Hurghada in the north to Marsa Halaib, located on the Sudanic-Egyptian border. The coastal region exhibits distinct zonation patterns with regard to two mangrove species. *Avicennia marina* dominates the northern zone, spanning from Hurghada to Marsa El-Madfa. Conversely, the southern zone, extending from Marsa El-Madfa to Marsa Halaib, showcases a co-dominance of *Avicennia marina* and a replacement of this species by *Rhizophora mucronata* (**Zahran, 1982**). The geographical coordinates of the site are 27.727439° N latitude and 34.247299° E longitude. A narrow stretch of land near Ras Mohammed, approximately 1 kilometer in length, harbors a small grove of *Avicennia marina*. This strip is situated along a fault line and comprises sand, providing a substantial foundation for a dense mangrove branching structure (**Elnaggar *et al.*, 2022**).

Heavy metals, persistent chemicals introduced into marine environments, have the potential to increase heavy metal levels within coastal ecosystems including mangrove forests. Extensive research has focused on the ability of mangrove forest sediments in tropical and subtropical locations to sequester heavy metals from water (**Tam & Wong, 1996; Clark *et al.*, 1998; Kamaruzzaman *et al.*, 2008**). The physicochemical characteristics of these sediments, such as their predominantly anaerobic nature and high organic content, contribute to the effective absorption and retention of heavy metals (**Harbison, 1986; Qiu *et al.*, 2011**). Consequently, these sediments serve as reliable indicators of heavy metal content (**Tam & Wong, 2000**). **Defew *et al.* (2005)** suggest that sediment deposition can transport the aforementioned pollutants to mangrove trees.

Given the above information, conducting comprehensive measurements of heavy metal concentrations in both plant tissues and sediments across various regions is crucial. This approach enables effective monitoring of the environment and ensures adequate protection of mangrove trees from potential heavy metal pollution.

The mangrove vegetation in the study area encompasses various components, including trunks, aerial roots, leaves, and the extensive shade cast by the trees. These mangroves typically thrive in close proximity to lagoons and channels, which are in turn, adjacent to shallow subtidal sand and mud flats. These flats often feature seagrass beds and fringing reefs, creating diverse habitats and biotopes. Furthermore, these areas support a wide array of fish species and are inhabited by various forms of biota (**Elnaggar *et al.*, 2022**). Therefore, the aim of this study was to investigate the occurrence of heavy metal contamination in the sediments of mangrove vegetation located in Ras Muhammed's protectorate, the Red Sea. In addition, the research sought to evaluate the ecological implications linked to heavy metals present in the sediment of mangrove ecosystems within the designated study area.

MATERIALS AND METHODS

Study area

The Ras Mohammed protectorate is a designated area of land that holds recognition and protection due to its ecological and environmental significance. Situated at the southernmost point of the Sinai Peninsula, Ras Mohammed National Park is in close proximity to the Red Sea, bordered by the Gulf of Suez on one side and the Gulf of Aqaba on the other (**Frouda, 1984)**. **Shehata (1998)** described that the coastal plain exhibits a narrow width, characterized by granitic mountains that gradually descend towards the sea.

The park's establishment took place in 1983, signifying a notable milestone as Egypt's first national park. However, scholars such as **Shehata (1998)** agree that the area was largely considered a "paper park" until 1988 when the Egyptian government entrusted the management of the park to the Egyptian Environmental Affairs Agency (EEAA). This decision was prompted by the increasing popularity of the region as a diving touristic destination. Fig. (1) illustrates the sampling locations of this area as Egypt's inaugural national park.

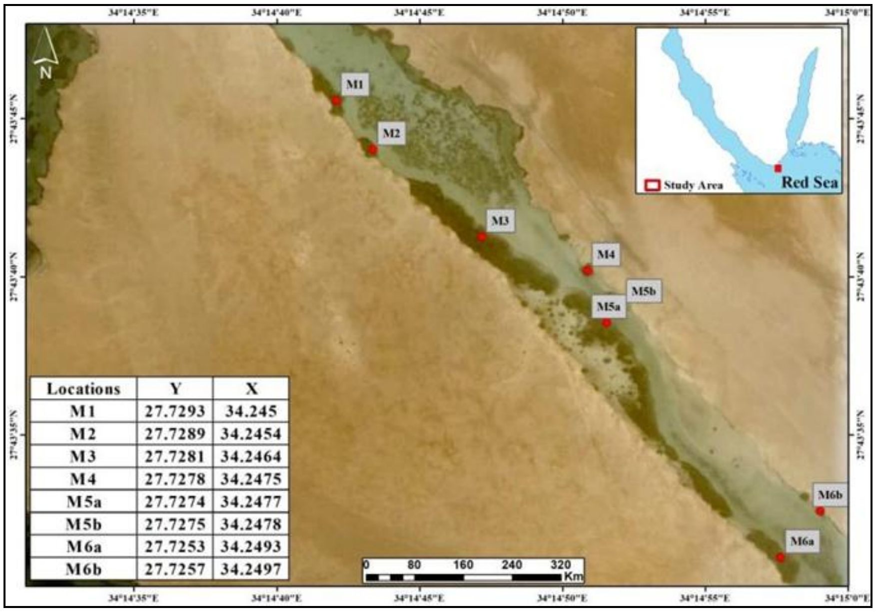
Encompassing a total area of 480km^2, the Ras Mohammed National Park (RMNP) is divided into two distinct sections: a marine portion covering approximately 70% of the park's total area, which includes a significant portion of the Gulf of Suez and the Gulf of Aqaba, and a terrestrial section constituting the remaining 30%. The park includes two sea islands, Tiran and Sanafir, which serve as important ecological habitats for numerous species. These islands are heavily utilized by sea birds and marine turtles for nesting purposes due to the absence of predators and minimal disturbance (**Shehata, 1998)**.

Within the Ras Mohammed protectorate, each island represents a unique natural evolutionary experiment, providing valuable insights into the ecological history of the surrounding area. The park showcases distinctive marine and terrestrial assets, and its exceptional geographic location has facilitated the development and ongoing preservation of diverse species and habitats.

The Ras Mohammed protectorate has gained international acclaim due to its diverse and abundant natural habitats, particularly the coral reef environment, renowned as one of the world's finest. This has made it a popular destination for tourists in the Sharm El Sheikh region, especially among SCUBA divers. The coral reef ecosystem in RMNP is recognized globally as an exceptional example of a high diversity of coral species. The presence of 220 species exhibiting a variety of colors and shapes within a confined geographical area distinguishes the locale, making it a unique environment. Moreover, the region is home to three endangered species of sea turtles, such as the green turtle, the loggerhead turtle, and the hawksbill turtle. Additionally, it supports the survival of the at-risk white storks and endangered mangrove species, specifically *Avicennia marina* (**Abu Bkr & El-Hussieny, 2007)**.

The park serves as a crucial habitat for a wide array of significant marine species, including various fish species, sponges, snails, and crabs. Avian species, such as storks, waders, and herons hold significant ecological value within the designated region. A comprehensive survey has documented the presence of approximately 241 distinct bird species, encompassing both migratory and resident populations.

Within the park, seagrasses, mangroves, and vegetation serve as vital habitats for a diverse range of organisms, including turtles, fishes, shrimps, crabs, birds, and rodents. As a result, it has become a prominent destination for tourism and recreation, renowned as a premier location for diving and research endeavours (**Abu Bkr & El-Hussieny, 2007)**.



Locations	Y	X
M1	27.7293	34.245
M2	27.7289	34.2454
M3	27.7281	34.2464
M4	27.7278	34.2475
M5a	27.7274	34.2477
M5b	27.7275	34.2478
M6a	27.7253	34.2493
M6b	27.7257	34.2497

Fig. 1. A map of Ras Mohammed illustrating the specific sampling locations

Sampling and analysis

Within the Ras Mohammad protectorate, a total of eight sediment sampling sites were established based on the water system map of the study area and field observations. To ensure the collected samples' representativenes, each sampling site was positioned using a portable Global Positioning System (GPS) device (Garmin 72, Lenexa, KS, USA).

The sediment samples underwent air drying at ambient temperature and pulverization using an agate mortar. The quantification of the combined concentrations of heavy metals (Fe, Mn, Zn, Cu, Pb, and Cd) in the sediment samples followed the UNEP/IAEA guidelines established in 1986. Approximately, 0.5g of the dry sample was completely digested in Teflon containers using a mixture of HNO3, HF, and HClO4 at a volumetric ratio of 3:2:1. To ensure precision, duplicate digestions were performed for each sample. The resulting solution was diluted to a volume of 25ml using distilled de-ionized water. Triplicate analysis of the digested solutions was conducted using an atomic absorption spectrophotometer (AAS Perkin Elmer analyzer, Model 100). The obtained values were reported in micrograms per gram of dry weight.

The accuracy and precision of the analysis were verified using reference material, specifically SD-M-2/IM. The analytical results from the quality control samples demonstrated a satisfactory level of performance in determining heavy metals, falling within the authorized range of values. The recovery rates for the investigated metals ranged from 90.4% to 97.5%.

RESULTS AND DISCUSSION

Distribution of heavy metals of mangrove sediments

The influx of trace metals into estuarine and coastal habitats directly results from the rapid industrialization and economic growth witnessed in coastal regions worldwide (**Santos *et al.*, 2005**). Numerous studies have provided evidence of substantial contamination of coastal sediments by heavy metals. Hence, the assessment of marine pollution can be enhanced by examining the distribution of metals in surface sediments (**Jayaprakash *et al.*, 2008)**. These metallic elements actively participate in various biogeochemical processes characterized by their notable mobility. The potential impacts of these mechanisms on ecosystems can be observed through the processes of bioaccumulation and biomagnification, which pose threats to both human and environmental well-being (**Elnaggar *et al.*, 2022**).

Table 1. The statistical measures of heavy metal concentrations (µg/ g) within Ras Mohammed protectorate, including the mean, standard deviation, minimum, and maximum values

Metal	Mean	± SD	Min	Max	CV	TEL	PEL
Cu	1.999	0.56	0.87	2.453	0.28014	18.7	108.2
Fe	96.89	41.28	30.32	149.4	0.42605		
Pb	13.856	1.24	11.86	15.81	0.08949	30.2	112
Cd	1.47	0.15	1.31	1.724	0.10204	0.68	4.21
Zn	12.62	3.34	8.51	19.83	0.26466	124	271
Mn	37.2	14.97	16.86	62.93	0.40242		

CV: Coefficient of Variation, TEL: Threshold Effect Level, PEL: Probable Effect Level

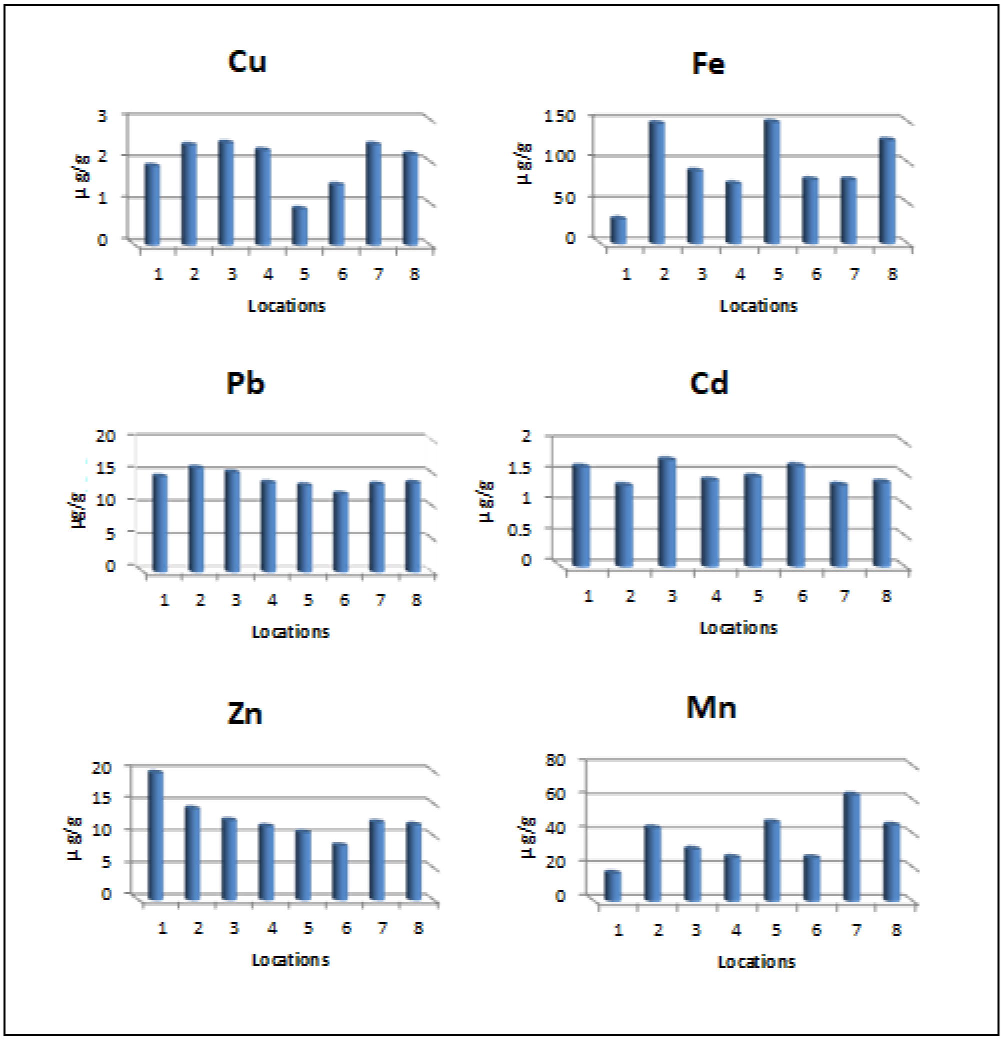


Fig. 2. The spatial distribution of heavy metals throughout the sediment of the mangrove ecosystem located at Ras Mohammed (RM) of the Gulf of Aqaba

The present investigation offers an analysis of the spatial distribution and intrinsic properties of heavy metals, namely copper (Cu), iron (Fe), cadmium (Cd), lead (Pb), zinc (Zn), and manganese (Mn), within the sedimentary deposits of the Mangrove ecosystem situated in Ras Mohammed, located in the Gulf of Aqaba. A detailed graphical representation of these findings can be observed in Fig. (2), while the average values tabulated data are available in Table (1). The data revealed that copper (Cu) exhibited a peak concentration of 2.45µg/ g at location (3), whereas the lowest concentration of 0.87µg/ g was observed at position (5). The average concentration across all locations was approximately 1.99± 0.56µg/ g. Copper primarily originates from sources such as desalination plants, vessel traffic, maritime operations, ship maintenance, and the use of antifouling coatings (**Sallam *et al.*, 2013**). In comparison to reported values for the crustal average (55mg/ kg) by **Taylor (1964)**, the mean crust (50 mg/ kg) stated by

Bowen (1979), and the upper crust (25mg/ kg) documented by **Taylor and Mclennan (1995)**, the sites within our study region are considered to be free from pollution.

Iron (Fe) was found to be the most abundant metal analyzed, and total iron levels varied significantly among the various sites. The highest recorded concentration of iron (Fe) was 149.4µg/ g at location (5), whereas the lowest concentration was 30.32µg/ g at location (1). The average concentration across all locations was calculated to be 96.89µg/ g. The sediment samples collected in the research area exhibited a lower concentration of Fe, compared to the average composition of the Earth's crust, as reported by **Taylor (1964)**. Furthermore, the Fe concentration in these sediments was also found to be lower than that of the upper crust, as documented by **Taylor and Mclennan** (**1995)**, as well as the mean crust, as described by **Bowen (1979)**. The sediments within the Ras Mohamed protectorate are widely regarded as being pollution-free.

The findings indicate that the recorded values were comparatively lower than those reported by **Salem *et al.* (2014)** for the Red Sea coast in Egypt, which fell within the 398.1–10413.6mg/ kg range. Similarly, the values were lower than those reported by **El Nemr *et al.* (2006)** for the Gulf of Suez, ranging from 384.6–13549.3mg/ kg, as well as the findings by **Mansour *et al.* (2013)** for the Hurghada area in the northern Red Sea, Egypt, which ranged from 0.00–12300mg/ kg.

The Lead (Pb) values varied between 11.86µg/ g at site (6) and 15.18µg/ g at location (2), with an average concentration of 13.856µg/ g. The elevated levels of Pb concentrations observed in the research area can potentially be attributed to the discharge of Pb resulting from both human activities and maritime operations. These activities encompass a range of sources such as oil spills, using outboard boat engines, the transportation of coal, shipyard operations, corrosion processes, antifouling coatings, and improper disposal of untreated waste materials.

In comparison with the average shale **(Turekian & Wedepohl, 1961**) with a concentration of 20mg/ kg, and the mean sediment (**Salomons & Forstner, 1984**) with a concentration of 19mg/ kg, and the upper crust **(Taylor & Mclennan, 1995)** with a concentration of 20mg/ kg, the sites within the analyzed area can be classified as unpolluted. The concentration of lead in the sediments of the research area was found to be in line with typical levels, indicating that it represents the background concentration of lead in sediments.

In their study, **Sadiq *et al.* (2003)** found that even small amounts of lead can adversely affect marine species when compared to other heavy metals. The findings of **Younis *et al.* (2014)** indicate that our results exhibit a lesser magnitude when compared to their study conducted along the coast of the Red Sea in Egypt. Similarly, the investigations conducted by **Mansour *et al.* (2000)** along the Red Sea coast in Egypt, **El Nemr *et al.* (2006)** in the Gulf of Suez, and **Mansour *et al.* (2007)** along the coast of Hurghada in the Red Sea, Egypt, all reported higher values than our findings.

In the current investigation, the concentration of cadmium (Cd) was measured, with the highest recorded concentration being 1.72µg/ g at location (3) and the lowest concentration of 0.98µg/ g at location (2). The average cadmium concentration across all sites was approximately 1.32± 0.28µg/ g. The levels of cadmium observed in the sediment samples from Ras Mohammed are higher compared to the reported average crustal abundance of 0.1mg/ kg by **Taylor (1964)**, the mean crust concentration of 0.2mg/ kg reported by **Bowen (1979)**, and the upper crust concentration of 0.5mg/ kg reported by **Taylor and Mclennan (1995)**. Cadmium concentrations in the sediments of Ras Mohammed can be considered within the unpolluted range.

On the other hand, zinc concentrations varied between 62.93µg/ g at location (1) and 16.68µg/ g at location (6), with an average concentration of 37.2± 14.97µg/ g. The zinc levels in the sediment samples from the study area are generally lower compared to the average crustal abundance of 70mg/ kg reported by **Taylor (1964)**, the mean crust concentration of 70 mg/ kg reported by **Bowen (1979)**, and the upper crust concentration of 70 mg/ kg reported by **Taylor and Mclennan (1995)**. The zinc concentrations in the sediments of Ras Mohammed can be considered within the background range.

Manganese concentrations ranged from 16.68µg/ g at location (1) to 62.93µg/ g at location (7), with an average concentration of 37.2± 14.97µg/ g. The manganese levels in the sediment samples from the study area are lower compared to the average crustal abundance of 950mg/ kg reported by **Taylor** (**1964)**, the mean crust concentration of 950 mg/ kg reported by **Bowen (1979)**, and the upper crust concentration of 950mg/ kg reported by **Taylor and Mclennan (1995)**. The manganese concentrations in the sediments of Ras Mohammed can be considered within the background range.

Overall, the heavy metal concentrations in the sediment samples from the Mangrove ecosystem in Ras Mohammed indicate that the area is relatively pollution-free. However, it is important to continue monitoring and assessing the environmental conditions to ensure the long-term health and sustainability of the ecosystem.

Quality guidelines for sediment (SQG)

The sediment quality guidelines (SQG) encompass standards and criteria for assessing sediment quality in diverse environmental contexts. These guidelines are formulated to establish a framework for evaluating the potential risks and impacts associated with sediment. Heavy metal pollution in the natural environment that poses a substantial global threat. The influx of heavy metals into the aquatic ecosystem, originating from both natural and anthropogenic sources, is a recurring issue. This occurrence is of a significant concern due to the inherent toxicity, prolonged presence, and capacity for bioaccumulation within organisms **(Chon *et al.*, 2010)**.

In comparison to water, sediment displays a higher level of conservatism due to its capacity to preserve valuable historical information regarding the dynamics of water bodies and the impact of human activities on these dynamics. Consequently, sediment quality metrics have been employed as indicators of environmental conditions, widely recognized for their efficacy in detecting and monitoring sources of contamination. According to **de Vallejuelo *et al.* (2010)**, sediment possesses the capability to absorb and subsequently incorporate the relatively small quantities of heavy metals present in water.

Sediments possess the capacity to function as both a source and a reservoir for harmful compounds. Over the past decade, several sediment quality guidelines (SQGs) have been developed with the objective of safeguarding aquatic organisms residing in or near sediments from the detrimental impacts of pollutants bound to sediments (**MacDonald *et al*., 2000; McCready & Birch, 2006**). These guidelines also serve the purpose of predicting unfavorable biological outcomes in contaminated sediments. The criteria encompass both sediment quality objectives and sediment quality standards. The guidelines presented by **MacDonald *et al.* (2000)** facilitate the assessment of regional disparities in sediment pollution, categorizing sediment contamination levels, formulating monitoring initiatives, analyzing historical data, and conducting environmental evaluations for prospective remedial endeavours.

McCready and Birch (2006) assert the existence of a multitude of sediment quality standards aimed at protecting aquatic biota from the deleterious effects of pollutants bound to sediments. These guidelines aim to assess sediment quality by evaluating the potential adverse effects of sediment chemical composition on aquatic organisms. Furthermore, **Díaz-de *et al.* (2011)** prioritized and ranked contaminated sites for further investigation.

The construction of SQGs involves utilizing three approaches: effect range, effect level, and apparent effect threshold. The careful selection of suitable soil quality guidelines (SQGs) is paramount. The numerical values obtained from these guidelines may vary significantly depending on the method employed for derivation, the calculations' intended purpose, and the guidelines' ability to align with the specific geological conditions of the area under consideration (**MacDonald *et al.*, 2000)**.

The findings of the present study indicate that the concentrations of the metals investigated in the mangrove sediments of the Ras Mohamed protectorate were generally below the thresholds specified by the Canadian sediment quality recommendations, including the probable effect level (PEL) and the threshold effect level (TEL). However, it is noteworthy that the cadmium (Cd) concentration exceeded the TEL value of 0.68µg/ g. The analysis of heavy metal distribution revealed that the Cd concentration surpassed the TEL, indicating a potential for adverse effects on environmental quality. This could be attributed to the observed increase in recreational activities within the study area (Table 1).

Evaluation of pollution indices

The geo-accumulation index (Igeo)

The geo-accumulation index (Igeo) is a fundamental metric employed in the present study to assess the levels of heavy metal contamination in sediment samples. It was first introduced by **Müller** (**1969)**. The geo-accumulation index (Igeo) serves as a method for assessing and characterizing the presence of metal pollution within sedimentary environments. The subsequent equation elucidates the concept of the geo-accumulation index (Igeo):

$$\text{Igeo} = \text{Log}^2 \left(\frac{\text{Cn}}{1.5 \text{ X } \text{B}_\text{n}} \right)$$

In the above equation, Cn refers to the measured concentration of the metal in the sediment. At the same time, Bn represents the geochemical background concentration of the metal as determined by **Turekian and Wedepohl (1961)**. The factor for adjusting the background matrix due to variations in lithology is 1.5. The background concentrations of the metals are equivalent to the values derived from the enrichment factor calculations. A geo-accumulation index, similar to the metal enrichment factor, has been proposed to assess the degree of metal contamination (**Zhang *et al.*, 2009**). Müller categorized the geo-accumulation index into seven distinct classes, ranging from class 0 (indicating an Igeo value of 0) to class 6 (indicating an Igeo value greater than 5). The Igeo, or the index of geoaccumulation, is a qualitative metric employed to assess pollution intensity. Samples are classified into different categories based on their Igeo values including unpolluted.

The Igeo, or the index of geoaccumulation, is a qualitative metric employed to assess pollution intensity. Samples are classified into different categories based on their Igeo values, including unpolluted (Igeo≤ 0), unpolluted to moderately polluted (0< Igeo≤ 1), moderately polluted (1< Igeo≤ 2), moderate to strongly polluted (2< Igeo≤ 3), strongly polluted (3< Igeo≤ 4), strongly to extremely polluted (4< Igeo≤ 5), and extremely polluted (Igeo> 5). Class 6 exhibits a minimum enrichment of 100 times compared to the values seen in the background, as show in Table (2).

Table 2. Geo–accumulation index (Igeo) **(Muller 1979)**

I_{geo} value	I_{geo} class	Pollution level
≤ 0	0	Unpolluted
0 ─ 1	1	Unpolluted to moderately polluted
1 ─ 2	2	Moderately polluted
2 ─ 3	3	Moderately polluted to highly polluted
3 ─ 4	4	Highly polluted
4 ─ 5	5	Highly polluted to very highly polluted
> 5	6	Very highly polluted

The calculated geo-accumulation index (Igeo) values are presented in Table (2). The graphical representation of the data clearly demonstrates that the Igeo values for Cu, Pb, Cd, Zn, and Mn consistently fall within the range of class "1," indicating unpolluted to moderately polluted conditions across all investigated sites. This observation implies that these metals have either negligible contributions to pollution or contribute to a moderate extent. The highest recorded Igeo value was 0.339, which was observed for zinc (Zn) at location (1) within the Ras Mohammed protectorate (Table 3).

Table 3. Igeo values of the distribution of metals in the surface sediments along the Ras Mohamed protectorate

Location	Cu	Pb	Cd	Zn	Mn
1	0.159	0.219	0.223	0.339	0.050
2	0.201	0.239	0.181	0.244	0.130
3	0.205	0.228	0.288	0.213	0.093
4	0.190	0.205	0.193	0.197	0.078
5	0.073	0.199	0.201	0.181	0.140
6	0.121	0.179	0.225	0.145	0.077
7	0.202	0.201	0.185	0.207	0.188
8	0.202	0.204	0.188	0.201	0.135

Metal pollution index (MPI)

The metal pollution index (MPI) serves as a quantitative metric utilized to evaluate the extent of metal contamination within a given environmental setting. This index enables the amalgamation of metal concentrations into a singular value, facilitating comparisons of overall metal content across diverse geographical regions. **Teodorovic *et al.* (2000)** derived the equation employed for MPI calculations, expressed as follows:

$$MPI = (Cf1 * Cf2 ******* Cfk)^{(1/k)}.$$

In this equation, Cf1 represents the concentration value of the first metal, Cf2 denotes the concentration value of the second metal, and Cfk signifies the concentration value of the kth metal.

Additionally, **Tomlinson *et al.* (1980)** and **Harikumar *et al*. (2009)** have conducted investigations to determine the pollution load index (PLI) values for metals. In their respective studies, a PLI value exceeding 1 indicates the presence of pollution, while a value below 1 suggests the absence of pollution.

The outcomes obtained from the MPI assessment reveal that the values surpassing 1 were predominant in the sampling sites within the Ras Mohammed regions. Specifically, locations 2, 3, 5, 6, and 7 in Ras Mohammed exhibited MPI values greater than 1. The findings derived from this study imply the existence of a current burden of metal contamination, as illustrated in Fig. (3).

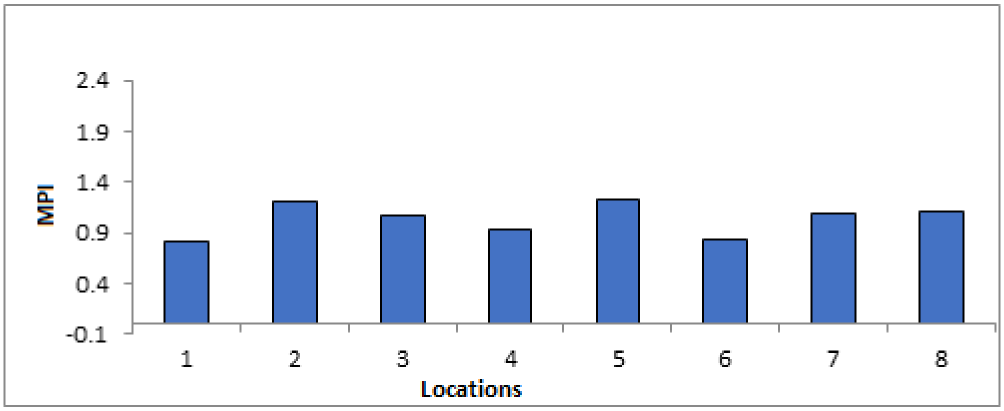


Fig. 3. The sediment quality assessment for the Ras Mohammed protectorate using multi-element indices (MPI: Modified pollution index)

The potential ecological risk index (PERI)

The study employed the potential ecological risk index (PERI) proposed by **Hakanson (1980)** to evaluate the potential harm associated with the metals under investigation. The PERI serves the purpose of assessing the potential impact on ecological well-being stemming from the introduction of pollutants that have the potential to propagate through the food chain. The designated equation was utilized to calculate both the potential ecological risk coefficient of each individual metal and the cumulative impact of multiple metals, resulting in the potential ecological risk index (PERI).

$$PERI = \sum_{i=1}^{n} E_r^i$$

Determining sedimentary metal background levels in this study involved selecting the average shale background concentrations of global sediments, as reported by T**urekian and Wedepohl (1961)**. This decision was made due to the absence of relevant background-level data for metals specific to the analyzed location.

Hakanson (1980) proposed a classification system for the potential ecological risk index (PERI), consisting of four distinct categories. These categories are defined as follows: PERI values below 150 indicate a low ecological risk, while values between 150 and 300 suggest a moderate risk. If the PERI values range from 300 to 600, it signifies a high ecological risk. Values equal to or greater than 600 indicate a significantly high ecological risk. The ecological risk index of each individual element can be classified into several risk levels based on their respective values, including low risk (EIr< 40), moderate risk (40< EIr< 80), considerable danger (80< EIr< 160), high risk (160< EIr< 320), and very high risk (EIr> 320).

The results of estimating the potential ecological PERI for sediment samples from the study area are depicted in Fig. (4). The calculated PERI values for the Ras Mohamed region were 38.35, representing the lowest value observed at location (5), and 47.94, representing the highest value recorded at location (3). This observation may potentially be attributed to elevated levels of heavy metal concentrations in this specific area. According to **Hakanson (1980)**, the findings suggest a minimal ecological risk across all sites, as determined by the PERI calculations.

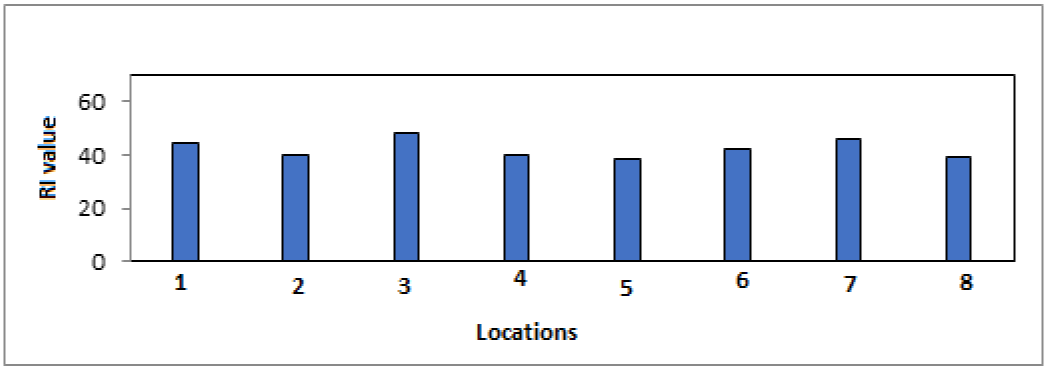


Fig. 4. Potential ecological risk index (PERI) of heavy metals in sediments of Ras Mohamed protectorate

The ecological risk factors (EIr) associated with the presence of heavy metals in the investigated sediment area are depicted in Fig. (5). The assessment values of EIr for all metals observed at sampling points in Ras Mohamed were below 40. According to the classification of **Hakanson (1980)**, these metals have minimal ecological impact in the examined area. However, it is worth noting that Cd at position 4 presents a moderate risk with a value of 48.96.

The ordering of the average potential ecological risk factor coefficients (EIr) for each metal examined in the sediments of the study area is as follows: In Ras Mohamed, the concentrations of heavy metals follow the order of Cd > Pb > Cu > Zn > Mn.

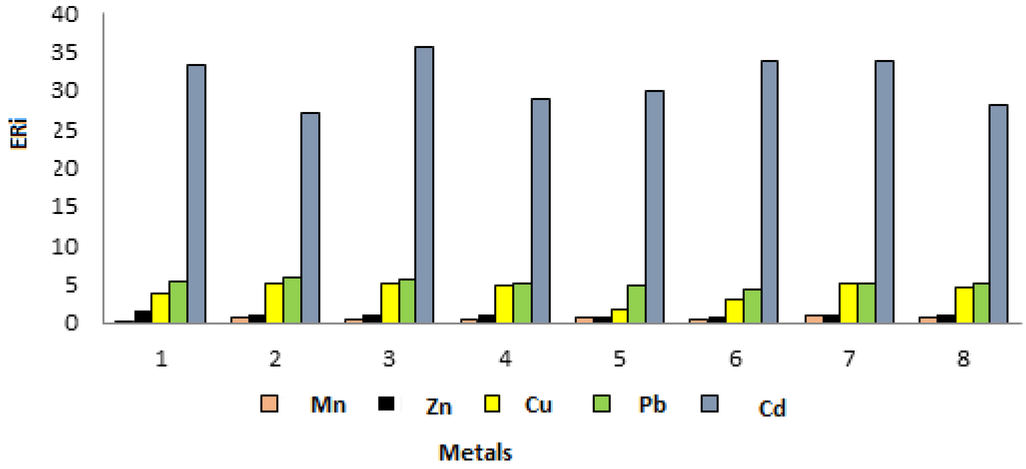


Fig. 5. The values of the ecological risk index factor (Eri) for heavy metals in the Ras Mohammed area

Toxic unit (TU)

The term "Toxic Unit" (TU) is commonly used in academic discourse to denote a specific concept or entity characterized by its toxic nature.

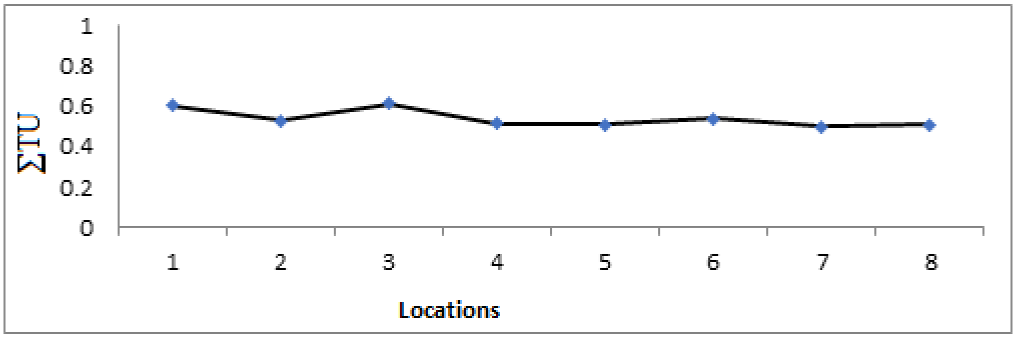


Fig. 6. The Toxic Unit (∑TU) values for metals at various locations along Ras Mohammed protectorate

The calculation of sediment TU was carried out by **MacDonald *et al.* (1996)** using the ratio between the observed metal content and the likely effect level (PEL). The estimation of potential acute toxicity resulting from heavy metals in sediment involves summing the toxic units (TU), which represent the potential acute toxicity of these metals in the sediment.

According to the sediment quality guidelines established by **Long *et al.* (1998)**, the PEL is defined as the concentration at which adverse consequences are expected to occur. Fig. (6) illustrates the range of ∑TU values for sediment in the research area, ranging from 0.5 to 0.61. These values were influenced by the concentrations of Cu, Pb, Cd, and Zn. Additionally, Fig. (6) compares the average percentage contribution of each metal to potential acute toxicity. It was observed that Cd has the highest contribution at 65%, followed by Pb at 22.9%, Zn at 8.59%, and Cu at 3.4% for the Ras Mohamed protectorate area. Moreover, the results in Fig. (7) further supports this information.

The findings of this investigation indicate that the metals present in the study region do not pose a potential toxicity risk to aquatic life. This conclusion is based on the observation that the TU values, as **Pedersen *et al.* (1998)** reported, consistently remain below 4 in all locations.

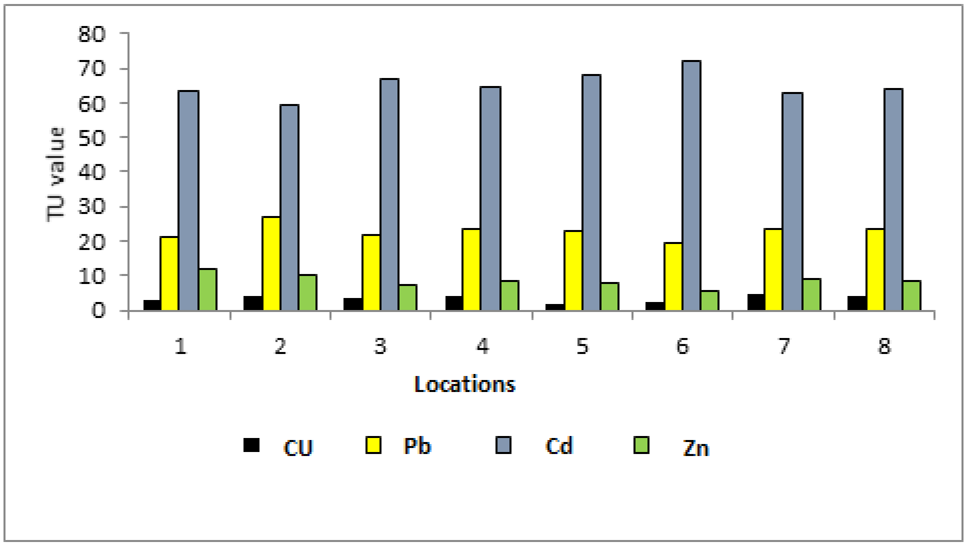


Fig. 7. The comparison of the Toxic Unit percentage (Tu%) for each heavy metal in the Ras Mohammed protectorate

CONCLUSION

In conclusion, aquatic environments globally serve as significant repositories for a wide range of contaminants, particularly heavy metals, which are primarily released into water bodies due to anthropogenic activities. These toxic substances have the potential to accumulate in aquatic organisms, leading to adverse effects on both human health and aquatic ecosystems. The Ras Mohammed protectorate in the Gulf of Aqaba holds ecological and environmental significance. It is characterized by specific spatial distribution and intrinsic properties of heavy metals within its sedimentary deposits. The analysis revealed varying copper, iron, cadmium, lead, zinc, and manganese concentrations across different sampling locations. The most heavy metal concentrations were within acceptable thresholds. The geo-accumulation index indicated unpolluted to moderately polluted conditions, with zinc exhibiting the highest contamination level. The metal pollution index highlighted elevated contamination in specific areas. The assessment of potential ecological risks indicated low toxicity risks to aquatic life in the study region. Overall, the findings emphasize the importance of implementing effective measures and regulations to mitigate heavy metal pollution, safeguard the environment, and protect both human and aquatic life in the Ras Mohammed protectorate.

REFERENCES

Bowen, H. J. M. (1979). Environmental chemistry of the elements, Academic Press.: London, UK, 333pp.

Chon, H.-S.; Ohandja, D.-G.; Voulvoulis, N.; and Implementation of EU. (2010). Water Framework Directive: source assessment of metallic substances at catchment levels. J. Environ. Monit., 12: 36-47.

Clark, M.W.; McConchie, D.; Lewis, D.W. and Saenger, P. (1998). Redox stratification and heavy metal partitioning in Avicennia-dominated mangrove sediments: a geochemical model. Chemical Geology, 149(3-4): 147-171.

de Vallejuelo, S. F. O.; Arana, G.; de Diego, A.; Madariaga, and Risk, J. M. (2010). Assessment of trace elements in sediments: the case of the estuary of the Nerbioi–Ibaizabal River (Basque Country). J. Hazard. Mater., 181: 565-573.

Defew, L. H.; Mair, J. M. and Guzman, H. M. (2005). An assessment of metal contamination in mangrove sediments and leaves from Punta Mala Bay, Pacific Panama. Marine pollution bulletin, 50(5): 547-552.

Díaz-de Alba, M.; Galindo-Riano, M.; Casanueva- Marenco, M.; García-Vargas, M.; and Kosore, C. (2011). Assessment of the metal pollution, potential toxicity and speciation of sediment from Algeciras Bay (South of Spain) using chemometric tools. J. Hazard. Mater., 190: 177-187.

El Nemr, A.; Khaled, A.; and El Sikaily, A. (2006). Distribution and statistical analysis of leachable and total heavy metals in the sediments of the Suez Gulf. Environ. Monit. Assess. 118: 89-112.

Elnaggar, D. H., Mohamedein, L. I., & Younis, A. M. (2022). Risk assessment of heavy metals in mangrove trees (Avicennia marina) and associated sea water of Ras Mohammed Protectorate, Red Sea, Egypt. *Egyptian Journal of Aquatic Biology & Fisheries*, *26*(5): 117-135.

El-Naggar, M., Hanafy, S., Younis, A.M., Ghandour, M.A. and El-Sayed, A.A.Y. (2021). Seasonal and temporal influence on polycyclic aromatic hydrocarbons in the Red Sea coastal water, Egypt. *Sustainability*, *13*(21): 11906.

Frouda, M. M. (1984). Ras Mohammed: The first National Park in Egypt. Courser. No. 1 the Ornithological Society of Egypt.

Hakanson, L. (1980). Ecological risk index for aquatic pollution control. A sedimentological approach. Water Res, 14:975–1001.

Hanafy, S.; Younis, A.M.; El-Sayed, A.Y. and Ghandour, M.A. (2021). Spatial, seasonal distribution and ecological risk assessment of Zn, Cr, and Ni in Red Sea surface sediments, Egypt. *Egyptian Journal of Aquatic Biology & Fisheries*, *25*(4): 513-538.

Haque, M.R.; Ahmad, J.U.; Chowdhury, M.D.A.; Ahmed, M.K. and Rahman, M.S. (2004). Seasonal variation of heavy metals concentration in sediments of the rivers and estuaries of Sundarban mangrove forest. *Asian Journal of Microbiology Biotechnology and Environmental Sciences*, *6*(2): 175-185.

Harbison, P. A. T. (1986). Mangrove muds—a sink and a source for trace metals. Marine Pollution Bulletin, 17(6): 246-250

Harikumar, P.S.; UP. Nasir, and Mujeebu R.M.P. (2009). Distribution of heavy metals in the core sediments of a tropical wetland system. Int. J. Environ. Sci. Technol., 6(2):.225-232.

Ilie, M., Marinescu; F., Szep, R.; Ghita, G.; Deak, G.; Anghel, A.M.; Petrescu, A. and Uritescu, B. (2017). Ecological risk assessment of heavy metals in surface sediments from the Danube River. Carpathian Journal of Earth and Environmental Sciences, 12(2): 437-445.

Jayaprakash, M.; Jonathan, M. P.; Srinivasalu, S.; Muthuraj, S.; Ram-Mohan, V.; and Rajeshwara-Rao, N. (2008). Acid-leachable trace metals in sediments from an industrialized region (Ennore Creek) of Chennai City, SE coast of India: An approach towards regular monitoring. Estuar. Coast. Shelf Sci., 76: 692-703.

Kamaruzzaman, B. Y.; Lokman, H. M.; Shazill, N. A. M. and Sulong, I. (2002). Geochemistry of some heavy metals as recorded in the sediment of the Kuala Kemaman Mangrove Forests, Terengganu, Malaysia. Oriental journal of Chemistry, 18(1): 7-14.

Long E. R. ; Field L.J.; MacDonald D. D. (1998). Predicting toxicity in marine sediments with numerical sediment quality guidelines. Environ Toxicol Chem 17: 714– 727.

MacDonald, D. D.; Ingersoll, C. G. and Berger, T. A. (2000). Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. Arch. Environ. Contam. Toxicol. 39: 20–31.

MacDonald, D.D.; Carr, R.S.; Calder, F.D.; Long, E.R. and Ingersoll, C.G. (1996). Development and evaluation of sediment quality guidelines for Florida coastal waters. Ecotoxicology, 5: 253–278

Mansour, A. M.; Askalany, M. S.; Madkour, H. A.; and Assran, B. B. (2013). Assessment and comparison of heavy-metal concentrations in marine sediments in view of tourism activities in Hurghada area, northern Red Sea, Egypt. Egypt. J. Aquat. Res., 39: 91-103.

Mansour, A. M.; Mohamed, A. W.; El Dien, G. K.; and Sayed, S. (2007). Sedimentological and environmental impacts of development projects along the coast of Hurghada, Red Sea, Egypt. Egypt. J. Aquat. Res., 33: 59–84.

Mansour, A.; Nawar, A. H.; and Mohamed, A. W. (2000). Geochemistry of coastal marine sediments and their contaminant metals, Red Sea, Egypt: A legacy for the future and a tracer to modern sediment dynamics. *Sedimentology of Egypt* 8: 231-242.

McCready, S.; Birch, G. F.; and Long, E. R. (2006). Metallic and organic contaminants in sediments of Sydney Harbour, Australia and vicinity — A chemical dataset for evaluating sediment quality guidelines. Environ. Int. 32: 455-465.

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

Öğlü, B.; Yorulmaz, B.; Genc, T.O. and Yılmaz, F. (2015). The assessment of heavy metal content by using bioaccumulation indices in European chub, Squalius cephalus (Linnaeus, 1758). Carpathian Journal of Earth and Environmental Sciences, 10 (2): 85 - 94

Panapitukkul,N.; Duarte,C.M.; Thampanya, U.; kheowvongsri,P.; Srichai,N.; Geet Z- Hansen,O.; Terrados, J. and Boromthamarth, S. (1998). Mangrove Colonization: Mangrove progression over the growing Park phanang (SE Thailand) mudflat.Estuarine, coastal and shef science, 47: 51-61**.**

Qiu, Y. W., Yu, K. F., Zhang, G., & Wang, W. X. (2011). Accumulation and partitioning of seven trace metals in mangroves and sediment cores from three estuarine wetlands of Hainan Island, China. Journal of Hazardous Materials, 190(1-3): 631-638.

Sadiq, R.; Husain, T.; Bose, N.; and Veitch, B. (2003). Distribution of heavy metals in sediment pore water due to offshore discharges: an ecological risk assessment. Environ. Modell. Softw., 18: 451- 461.

Salem, D. M. A.; Khaled, A.; El Nemr, A.; and El- Sikaily, A. (2014). Comprehensive risk assessment of heavy metals in surface sediments along the Egyptian Red Sea coast. Egypt. J. Aquat. Res., 40: 349-362.

Sallam, N. A.; El-Said, G. F.; and El-Sadaawy, M. M. (2013). Conservation measures and the effect of fluoride on an important common bivalve Paphia textile Gmelin, 1791 in Egyptian waters. Blue Biotechnol. J., 2: 595-609.

Salomons, W.; and Förstner, U. (1984). Metals in the Hydrocycle, Springer-Verlag: Berlin, Germany, 349.

Santos, I. R.; Silva-Filho, E. V.; Schaefer, C. E. G. R.; Albuquerque-Filho, M. R.; and Campos, L. S. (2005). Heavy metal contamination in coastal sediments and soils near the Brazilian Antarctic Location, King George Island. Mar. Pollut. Bull., 50: 185-194.

Shehata, A. (1998). Protected areas in the Gulf of Aqaba, Egypt: A mechanism of integrated coastal management. ITMEMS Proceedings.

Soliman, N., M Elkady, E. and M Younis, A. (2020). Chemical fractions and ecological risk of metals in sediments of the Bitter Lakes, Egypt. *Egyptian Journal of Aquatic Biology and Fisheries*, *24*(6): 167-196.

Taher, N.Z; Shabaka S.; Yosry A. Soliman and Younis, A. M. (2023). Assessment of microplastic pollution in the Gulf of Suez: Abundance and polymeric composition in beach sediments. *Egyptian Journal of Aquatic Biology & Fisheries*, *27*(4): 617-682.

Tam, N. F. Y. and Wong, Y. S. (1996). Retention and distribution of heavy metals in mangrove soils receiving wastewater. Environmental pollution, 94(3): 283-291.

Tam, N. F. Y. and Wong, Y. S. (2000). Spatial variation of heavy metals in surface sediments of Hong Kong mangrove swamps. Environmental pollution, 110(2): 195-205.

Taylor, S. R. (1964). Abundance of chemical elements in the continental crust: a new table. Geochim. Cosmochim. Acta, 28: 1273-1285.

Taylor, S. R.; and McLennan, S. M. (1995). The geochemical evolution of the continental crust. Rev. Geophys., 33: 241-265.

Teodorovic, I.; Djukic, N.; Maletin, S.; Miljanovic, B. and Jugovac, N. (2000). Metal pollution index: Proposal for freshwater monitoring based on trace metal accumulation in fish. Tiscia, 32: 55– 60.

Tomlinson, D.C.; J.G. Wilson, C.R. Harris; and Jeffrey, D.W. (1980). Problems in the assessment of heavy metals in estuaries and the formation pollution index. Helgol. Mar. Res. 33: 566-575. https://doi.org/10.1007/BF02414780

Turekian, K. K.; and Wedepohl, K. H. (1961). Distribution of the elements in some major units of the earth's crust. Geol. Soc. Am. Bull., 72: 175-192.

UNEP/IAEA. (1986) “Reference Methods for Marine Pollution Studies,” Athens.

Younis, A. M.; Ismail, I. S.; Mohamedein, L. I.; and Ahmed, S. F (2014). Spatial variation and environmental risk assessment of heavy metal in the surficial sediments along the Egyptian Red Sea coast. Catrina: Int. J. Environ. Sci., 10: 19-26.

Younis, A. M.; A Aly-Eldeen, M. and M Elkady, E. (2019). Effect of different molecular weights of chitosan on the removal efficiencies of heavy metals from contaminated water. Egyptian Journal of Aquatic Biology and Fisheries, 23(4): 149-158.

Younis, A.M. (2019). Environmental Impacts on Egyptian Delta Lakes’ Biodiversity: A Case Study on Lake Burullus. In: "Coastal Lakes and Wetlands: Part II: Climate Change and Biodiversity." Negm, A.M.; Bek, M.A. and Abdel-Fattah, S. (Eds.). Handbook of Environmental Chemistry, 72: 107-128. https://doi.org/10.1007/698_2017_120

Younis, A.M. (2020). Accumulation and rate of degradation of organotin compounds in coastal sediments along the Red Sea, Egypt. *Egyptian Journal of Aquatic Biology and Fisheries*, *24*(5): 413-436.

Y**ounis, A.M.; Hanafy, S.; Elkady, E.M.; Ghandour, M.A.; El-Sayed, A.A.Y. and Alminderej, F.M. (2023).** Polycyclic aromatic hydrocarbons (PAHs) in Egyptian red sea sediments: Seasonal distribution, source Identification, and toxicological risk assessment. *Arabian Journal of Chemistry*, *16*(9): 104999.

Younis, A.M.; Soliman, N.F.; Elkady, E.M. and Mohamedein, L.I. (2022). Distribution and ecological risk evaluation of bioavailable phosphorus in sediments of El Temsah Lake, Suez Canal, Oceanologia, 64(2): 287–298

Zahran, M. A. (1982). Ecology of the halophytic vegetation of Egypt. In Contributions to the Ecology of Halophytes (pp. 3-20). Dordrecht: Springer Netherlands.

Zhang, W.; Feng, H.; Chang, J.; Qu, J.; Xie, H.; and Yu, L. (2009). Heavy metal contamination in surface sediments of Yangtze River intertidal zone: An assessment from different indexes. Environ. Pollut. 157: 1533-1543.