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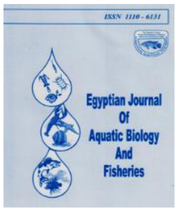

Environmental Risk Assessment for Heavy Metals Contamination in Seawater and Sediments from the Western Coast of Suez Gulf, Egypt

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ABSTRACT

The Suez Gulf is the most critical commerce corridor connecting the Middle East to the rest of the world due to its unique geographic location. Furthermore, it has an economic significance as a fishing and touristic area. These maritime activities have a detrimental effect on marine environments and are responsible for transmitting several harmful substances into the ocean. Therefore, assessing the degree of metal contamination in water and sediments at selected locations along the Suez Gulf from Port Tawfiq to Ras-Gharib is the main objective of this study. According to annual averages, an ecological risk assessment based on seawater quality standards in China and NOAA criteria indicated that these heavy metals did not pollute the Gulf water. Conversely, during the winter, the spatial fluctuations of eight heavy metals (Fe, Mn, Ni, Pb, Cd, Co, Zn, and Cu) in sediment samples were assessed. Several indicators, including the contamination factor (Cf), pollution load index (PLI), and geo-accumulation index (I_{geo}), were used to evaluate the level of contamination in the Gulf sediments. The results showed that the two biggest ecological threats were lead and mercury. Additionally, the levels of contamination varied from somewhat contaminated to very contaminated.

INTRODUCTION

The Suez Gulf has a significant maritime significance for Egypt, since it functions as a vital eastern access point for the global connectivity and acts as a prominent conduit for international commerce. Nevertheless, the Gulf's ecological integrity is compromised due to the proliferation of several ports with diverse operations, leading to pollution concerns **(Elgendy *et al.*, 2018)**. Heavy metals are widely acknowledged as a prominent category of water pollutants, posing significant risks to ecosystems and human well-being. Their long-lasting presence, toxicity, tendency to build up, and ability to strengthen biological effects make them harmful even at low levels **(Hossain *et al.*, 2021)**. Heavy metal concentrations in water change with the tides and other movements. This makes it easy for metal concentrations to spread quickly if there is not a steady flow of effluent **(Chakraborty & Owens, 2014)**.

Nevertheless, sediments are valuable indicators for monitoring heavy metals due to their relatively stable nature, making them less vulnerable to sudden temporal fluctuations. Furthermore, it has been shown that they possess a greater storage capacity than other reservoirs **(Hossain *et al.*, 2021).** As a result, these organisms can transfer and then adsorb contaminants from the aquatic environment **(Edokpayi *et al.*, 2016)**.

The potential impact of heavy metal leakage from sediments into the surrounding water on the ecological well-being of aquatic systems is a matter of concern **(Algül & Beyhan, 2020)**. Given the incorporation of heavy metals into the food web, the investigation of the presence of heavy metals in sediment has a major significance **(Patel *et al.*, 2018)**.

This research aimed to assess the extent of heavy metals contamination in water and sediments throughout significant regions spanning Port Tawfiq in the north to Ras-Gharib in the South along the Suez Gulf. Several other measures, including the contamination factor (Cf), the pollution load index (PLI), and the geological accumulation index (I_{geo}), were also used to figure out how dangerous heavy metal contamination in sediments was to the environment.

MATERIALS AND METHODS

1. Study area

The Suez Gulf is an important economic region for its distinctive and exceptional marine environment, contributing to its prominence as a fishing and tourism destination. Suez Gulf is a shallow part of the Red Sea. It spreads around 250km from Shadwan Island in the south (lat. 27° 36\) to the Suez port in the north (lat. 29° 56). The Gulf's width ranges from 20 to 40km, and its depth, which has a mean depth of 45m along its axis, is mainly consistent **(Elgendy *et al.*, 2018)**.

1.1 Sample collection

A total of fourteen sampling stations were strategically selected to provide a representation of various locations within the Suez Gulf. These stations were chosen to encompass the stretch of the coastline spanning approximately 225km, extending from Port Tawfiq in the northern region to Ras Gharib in the southern region. The individuals' whereabouts were determined using GPS technology, specifically the Garmin eTrex Vista HCx personal navigator (Fig. 1). The collection of subsurface water samples at depths ranging from 0 to 5 meters was conducted over the two principal seasons of winter and summer, 2019. The sampling was carried out using a purified PVC Niskin bottle. Similarly, a Van Veen grab sampler collected surface sediments (0- 10 cm) from the exact locations throughout the winter. Three sediment samples were collected from different locations at each site and combined to create a composite sample. The specimens were conveyed to the laboratory under refrigeration conditions and securely enclosed in polyethylene plastic. The samples were maintained at a temperature of 4°C until they underwent examination.

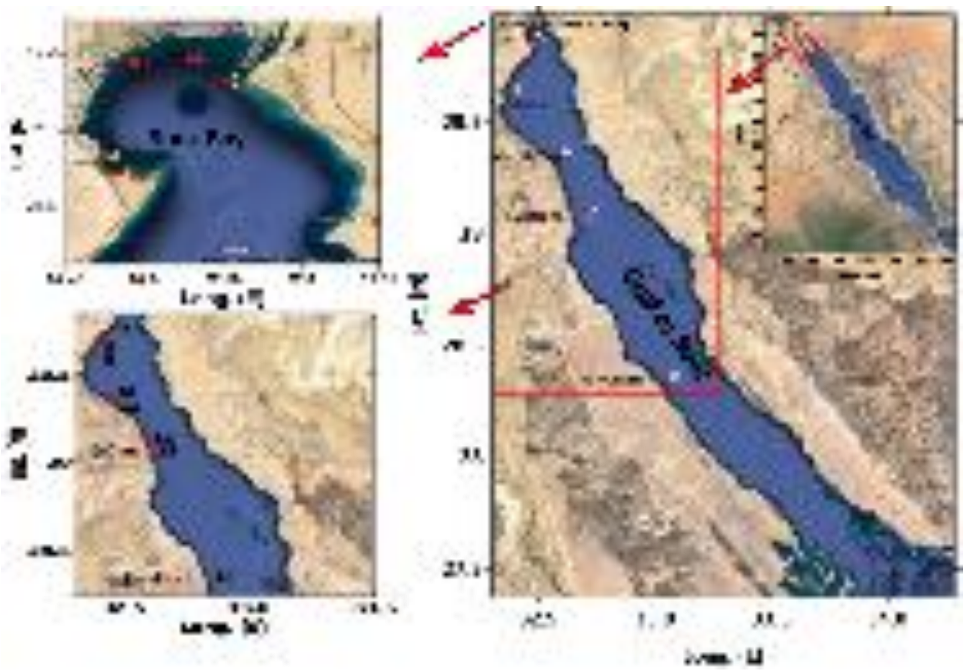


Fig. 1. Locations of sampling stations in Suez Gulf showing:
1- Port Tawfiq, 2-El-Zaitiya Harbour, 3-El-Kabanon Beach, 4-Adabiya Drainage, 5-Navigational Stream of Suez Canal, 6-Adabiya Longue, 7-Sand Beach, 8-New El-Sokhna Port, 9-Old El-Sokhna Port, 10-Abo Darg Head, 11-Abo Darg Lighthouse, 12-Zafrana 1, 13-Zafrana 2, and 14-Ras-Gharib

1.2 Sample analysis

A membrane filter with a thickness of 0.45m was used to filter the water samples. The ammonium pyrrolidine dithiocarbamate (APDC)/ methyl isobutyl ketone (MIBK) solvent extraction method was used following the method of **Eaton *et al.* (1995)** to separate heavy metals from seawater samples and concentrate them first. After that, a 50% nitric acid (HNO_3) solution was used to separate the metallic elements in the organic layer and then stored until they could be analyzed using atomic absorption spectrometry Perkin Elmer Model A Analyst 100 instrument.

In contrast, the sediments underwent a drying process lasting 48 hours at a temperature of 60°C in a thermostatically controlled oven. Subsequently, the sediments were homogenized using an agate pestle and mortar and passed through a sieve with a mesh size of 63µm. The fine sediment powder, weighing 0.5g, was digested in a dry Teflon beaker at 85°C. For the digestion process, a solution of HNO_3 and $HClO_4$ that was mixed in a 3:1 volumetric ratio was used faccording to the method of **Chester *et al.* (1994)**. The metals listed above, together with Co^{+2}, were subjected to analysis using Flame Atomic Absorption Spectroscopy (FAAS), as well as using a Perkin Elmer Type A Analyst 100 instrument. The results for sediments were reported as (mg/ kg) and water as (µg/ L). The heavy metal analysis was conducted in triplicate, and the average value of the results was reported.

All chemicals and acids used in the experiment were of Merck-GR grade. Moreover, all solutions were prepared using deionized water. Reference materials and reagent blanks were utilized to guarantee the dependability and correctness of the analytical results. The mean values of the recoveries of certified reference metals ranged from 97 to 104%.

1.3. Metal contamination evaluation

1.3.1. Seawater

The National Standard of China for Seawater Quality GB 3097-1997 **(SEPA, 1997)**, served as the study's criteria in the current study. The National Oceanic and Atmospheric Administration's **(Buchman, 2008)** reference table was also employed to quantify the ecological implications of heavy metals in seawater by considering their negative biological impacts.

1.3.2. Sediment

In order to assess the extent of metal pollution in sediments, three indices were employed: The contamination factor (Cf), the pollution load index (PLI), and the geo-accumulation index (I_{geo}). The analysis of the ecological status in the area under investigation placed particular emphasis on the distribution of harmful metals, nickel (Ni), lead (Pb), cadmium (Cd), cobalt (Co), copper (Cu), and zinc (Zn). However, iron (Fe) and manganese (Mn) were deemed unsuitable for this context due to their significantly lower concentrations compared to background levels, as stated by **(Hakanson, 1980)**.

1.4. Metal contamination indices

1.4.1. Contamination factor (Cf)

Contamination factor (Cf) was utilized to evaluate heavy metals in sediments, using the formula below following the method of the Swedish scholar **Hakanson (1980)** as follows:

$Cf= C_i/ C_b$ (1)

Where, C_i is the determined concentration (mg/ kg) of a particular heavy metal in the sediments; C_b is the background value (mg/ kg) of the given heavy metal, as outlined by **Turekian and Wedepohl (1961)**. The degree of pollution is measured as follows:

$Cf< 1$: Low contamination
$1\leq Cf< 3$: Moderate contamination
$3\leq Cf< 5$: Considerable contamination
$Cf\geq 5$: Very high contamination

1.4.2. Geological accumulation index (I_{geo})

The geological accumulation index (I_{geo}) was calculated to evaluate metal contamination in sediments by comparing present concentrations with pre-industrial levels. The equation is expressed as follows:

$I_{geo}= (C_i/〖1.5\ C〗b)$. (2)

Potential fluctuations in background data are considered using a factor of 1.5, as outlined by **Nour *et al.* (2019)**.

The degree of pollution is measured as follows:

$Igeo < 0$: Uncontaminated
$0 < Igeo < 1$: Uncontaminated/ moderately contaminated
$1 < Igeo < 2$: Moderately contaminated
$2 < Igeo < 3$: Moderately contaminated/ strongly contaminated
$3 < Igeo < 4$: Strongly contaminated
$4 < Igeo < 5$: Strongly contaminated/ extremely contaminated
$5 < Igeo$: Extremely contaminated

1.4.3. Pollution load index (PLI)

The following equation has established PLI to investigate the overall level of sediment pollution across sampling stations following the method used by **Xu *et al.* (2015)** as follows:

$$PLI=\llbracket\llbracket(Cf\rrbracket_{Ni}\times\llbracket Cf\rrbracket_{Pb}\times\ldots\ldots\llbracket Cf\rrbracket_{n})\rrbracket{}^{\wedge}(1/n) \qquad (3)$$

The degree of pollution is measured as follows:

$PLI \leq 1$: No pollution
$1 \leq PLI < 2$: Moderate pollution
$2 \leq PLI < 3$: Heavy pollution
$PLI \geq 3$: Extremely heavy pollution

1.5. Statistical analysis

The statistical analysis of the collected dataset was conducted using Microsoft Excel 2010 software. Pearson's correlation coefficient analysis was used to determine the relationship between heavy metals in the water and sediments. In addition, heavy metal content in seawater and sediments was subjected to one-way ANOVA and two-way ANOVA to understand pollution discharge conditions and possible sources better. A level of significance was defined as a probability of 0.05.

RESULTS

2.0 Heavy metals in seawater

In the present study, seven metals in the subsurface seawater of Suez Gulf were detected during winter and summer surveys (Table A.1 & Fig. 2). In accordance with A.1, the mean concentration of heavy metals decreased in the two seasons in the following order of Fe, Zn, Cu, Ni, Pb, Mn, and Cd. Metal concentrations across all sites varied from (12.26- 57.31), (0.05- 0.89), (0.43- 6.44), (ND- 2.47), (0.01- 1.10), (0.90- 3.82) and (2.04- 23.20) µg/ L with annual averages of 25.81, 0.26, 1.52, 0.98, 0.20, 2.02 and 10.21µg/ L, for Fe, Mn, Ni, Pb, Cd, Cu, and Zn, respectively. Station 4 recorded the highest concentrations of Mn (0.89µg/ L) and Ni (6.44µg/ L) during the summer and Pb (2.47µg/ L) during the winter. Station 5 was the polluted site, with the highest Zn contents (23.20µg/ L) during the winter and Fe (63.74µg/ L) during the summer. Stations

4 and 5 may be subjected to large volumes of sewage from domestic and industrial activity, which results in increased Fe, Mn, Ni, Pb, and Zn levels. Moreover, the subsurface water sample in Station 13 showed the highest Cd level (1.10µg/ L) during the summer. This significantly high Cd value could result from sewage, industrial spoils, ship repair, and other activities. Moreover, another potential source of heavy metals in seawater is the dissolution of heavy metals from sediments **(Sun *et al.*, 2020)**. The highest concentration of Cu (3.82µg/ L) was observed in Station 14 during the winter.

Significant relationships between heavy metals were found in the seawater (Mn: Fe and Ni at R> 0.60, *P*< 0.01, and N= 28) and between Pb and Cu (R= 0.60, *P*< 0.01, and N= 28) according to the correlation analysis (Table A.2). These relationships indicated specific similar sources, primarily being home and industrial sewage near the Suez Gulf coast. A two-way ANOVA of the combined data from the winter and summer surveys, revealed no significant spatial variations in the dissolved heavy metal concentrations during the winter (F= 1.16; *P*< 0.05) and summer (F= 1.26; *P*<0.05), but there were significant solid differences between the metal concentrations during the winter (F= 80.96, F_{criti}= 2.22, and *P*< 0.05) and summer (F= 59.91, F_{criti}= 2.22, *P*< 0.05) seasons. However, there were significant solid differences between metals concentrations during the winter (F= 80.96, F_{criti}=2.22, *P*< 0.05) and summer (F= 59.91, F_{criti}= 2.22, *P*< 0.05). Moreover, three heavy metals, Mn, Ni, and Cd, presented seasonal solid variations based on one-way ANOVA analysis at a significance level of 0.05. Specifically, the mean concentrations of these heavy metals were higher in the summer season (0.41, 2.16, and 0.35µg/ L) than in the winter (0.11, 0.88, and 0.04µg/ L), respectively. The seasonal variations in waste discharges may have contributed to this result. Fig. (2) shows that Fe, Pb, Cu, and Zn levels did not show any seasonal variations (*P*> 0.05).

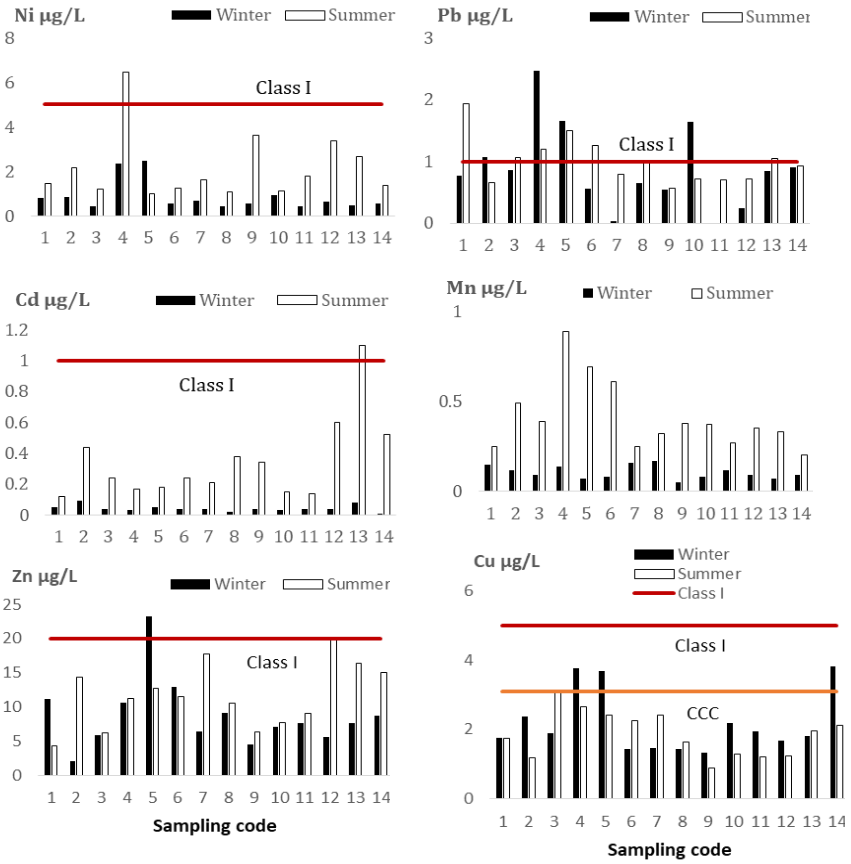


Fig. 2. Heavy metal concentrations in the Suez Gulf seawater during the winter and summer seasons

2.1 Assessment of heavy metal pollution in seawater

Table (A.3) shows that the average metal levels in the saltwater of the Suez Gulf mainly were the same as those found in other coastal areas, except for manganese (Mn).

2.2 Heavy metals in sediment

Fig. (3) illustrates the geographical distribution of heavy metals (mg/ kg) in sediment samples collected explicitly during the winter season. Additionally, Table (A.4) provides the corresponding information, including statistical data, about these samples. The eight elements that were determined in this study were iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), cadmium (Cd), cobalt (Co), copper (Cu), and zinc (Zn). The study's findings indicate that the sediments exhibit varying amounts of elements. Iron (Fe) had the highest average concentration, followed by zinc (Zn), lead (Pb), nickel (Ni), cobalt (Co), manganese (Mn), copper (Cu), and cadmium (Cd). The average concentrations of these elements were determined to be 225.07, 129.13, 87.80, 70.84, 51.11, 34.00, 22.36, and 12.80mg/ kg, respectively.

A Pearson correlation matrix was used to look at the sediment samples (Table A.5) in order to learn more about the relationships between metals and find the primary sources of heavy metals in the Suez Gulf. Significant correlation coefficients between metals might indicate a potential relationship between their anthropogenic and natural sources. The absence of any observed association between Cd and Zn in the present study, concerning other heavy metals and between themselves, is a noteworthy finding. This implies that their beginnings were separate. The significant effects seen at Station 2 strongly indicate that a substantial proportion of Cd and Zn may be attributed to human sources. Moreover, a significant correlation may exist between elevated cadmium (Cd) levels and inputs originating from terrestrial sources.

Pb, on the other hand, had a strong correlation with Ni, Co, and Cu ($P< 0.001$) but not as strong of a correlation with Fe ($P< 0.01$), which suggests that they came from the same place. The variable Ni exhibited a strong positive correlation with Co ($P< 0.001$), while displaying modest positive correlations with Cu and Fe ($P< 0.01$). Furthermore, a strong correlation was observed between Mn, Cu, and Fe ($P< 0.001$). The correlation between Fe and Cu was statistically significant ($P< 0.001$). Two distinct categories of metals were identified in the study: Nickel (Ni), cobalt (Co), lead (Pb), manganese (Mn), copper (Cu), and iron (Fe) originating from terrigenous sources. The highest levels of these metals were seen at Station 8, with relatively lower effects observed at Stations 7 and 9. Positive correlations suggest that the metals likely had a common origin and were distributed across the strata by comparable physicochemical processes: Stations St.8 and St.2 function as maritime ports for fishermen and commercial vessels. Hence, metal contamination in sediments may arise from activities like dredging, transportation operations, household and industrial sewage, and the deposition of waste in landfills. The current investigation revealed a positive skewness in the metal contents, except Co, as indicated in Fig. 4.

In addition, it was seen that, except for Mn and Co, the medians of the metal concentrations were lower than their corresponding mean concentrations. The presence of a positive skewness and the observation that the median values are lower than the means suggests that the distribution of metal content tends to be skewed towards lower concentrations of metals. On the other hand, the large standard deviations (ranging from 3.6 to 226.9) show that metal concentrations are very different in different areas. This could be because of human activities that cause these variables to be higher in some areas. Based on the results of the two-way ANOVA conducted on the winter survey data, it was found that there were statistically significant regional changes in heavy metal concentrations ($F= 2.05$, $F_{criti}= 1.83$, and $P< 0.05$) and very significant differences in the concentrations of different metals ($F= 10.05$, $F_{criti}= 2.11$, and $P< 0.05$).

2.3 Pollution assessment and ecological risk evaluation of heavy metals in sediments

To determine how bio-toxic sediments are, we use guidelines called the likely effects level (PEL) and the threshold effects level (TEL), found in Table (A.4) and Fig. (3). In the present investigation, Cd and Ni concentrations were above the permissible exposure limit (PEL) at all stations except Station 14, where only Ni concentrations surpassed the PEL. The concentrations of Cu and Zn in Stations 8 and 2, respectively, are above the permissible exposure limit (PEL). The Pb levels were also higher than the PEL in Stations (2, 7, and 8). This study's findings indicate that heavy metals in sediments, namely Cd, substantially impact the aquatic environment, leading to severe effects.

Information on the probable biological effects of heavy metals in Gulf sediments is shown in Fig. (5). In the current investigation, the contamination factors (Cf) exhibit low to moderate levels of contamination for nickel (Ni), ranging from 0.6 to 1.6, copper (Cu) from 0.1 to 2.9, and zinc (Zn) from 0.9 to 3.2. Furthermore, the contamination levels are moderate to significant for cobalt (Co), ranging from 1.6 to 3.5, and considerable to very high for lead (Pb), ranging from 3.3 to 7.9.

Moreover, according to the study's findings, the concentration factor (Cf) values ranging from 24.9 to 75.1 demonstrated a significant presence of cadmium (Cd) contamination. For the elements listed above, Station 1 had the highest coefficient (Cf) values for cobalt (Co), Station 2 had the highest values for zinc (Zn) and cadmium (Cd), and Station 8 had the highest values for nickel (Ni), lead (Pb), and copper (Cu). In general, Station 14 had the lowest recorded minimum Cf values. In Mabahiss Bay in north Hurghada, which is located in the Red Sea. According to a study by **Attia and Ghrefat (2013)**, they found significant levels of Cd pollution, moderate Pb and Co contamination, and no detectable Zn, Ni, or Cu contamination. The findings of this research are consistent with the results obtained in the current investigation. If you look at the average readings, you can see that the amount of Cd pollution (Cf= 42.67) was higher than the levels of other heavy metals. They were Pb (Cf= 4.39), Co (Cf= 2.69), Zn (Cf=

1.36), Ni (Cf= 1.04), and Cu (Cf= 0.50), in that order. Based on the mean values of Cf, it can be concluded that there is no detectable contamination with Ni and Cu. However, it is worth noting that several individual stations exhibited moderate contamination levels. Moreover, **Nour *et al.* (2019)** reported the same findings in their study conducted on the coastal sands of Shalateen in the Red Sea.

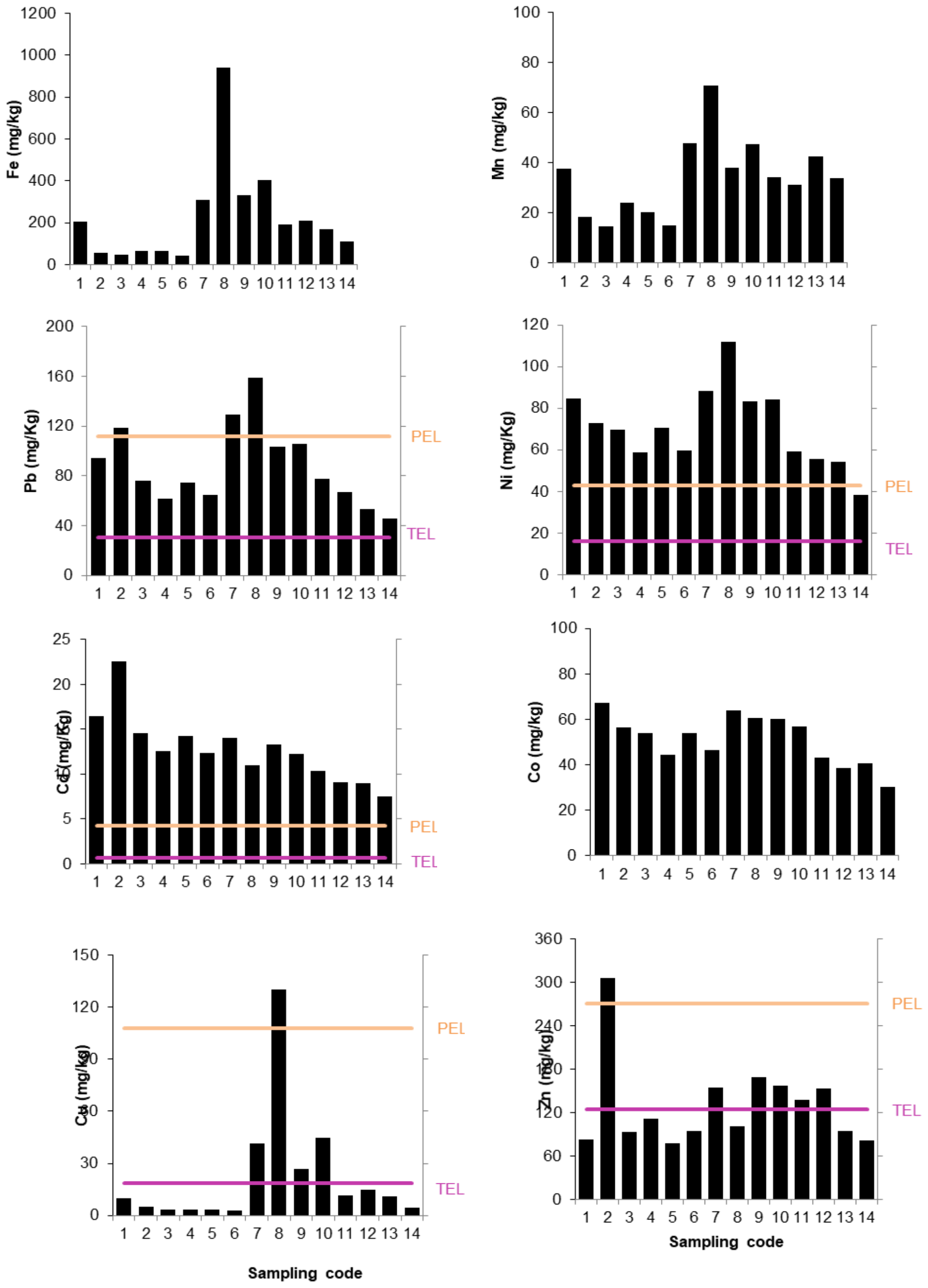


Fig. 3. Spatial variations of heavy metals in Suez Gulf sediment during the winter season

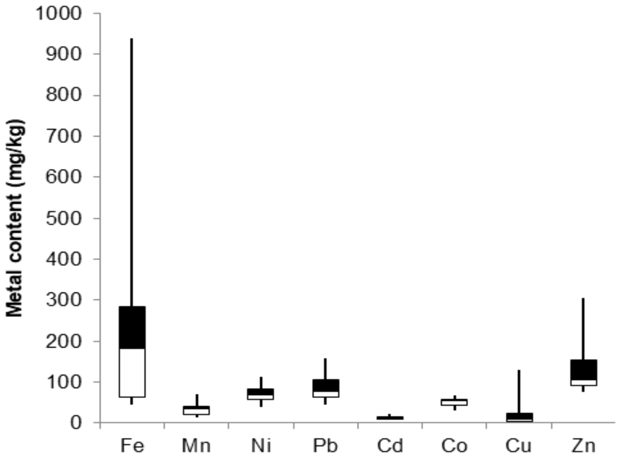
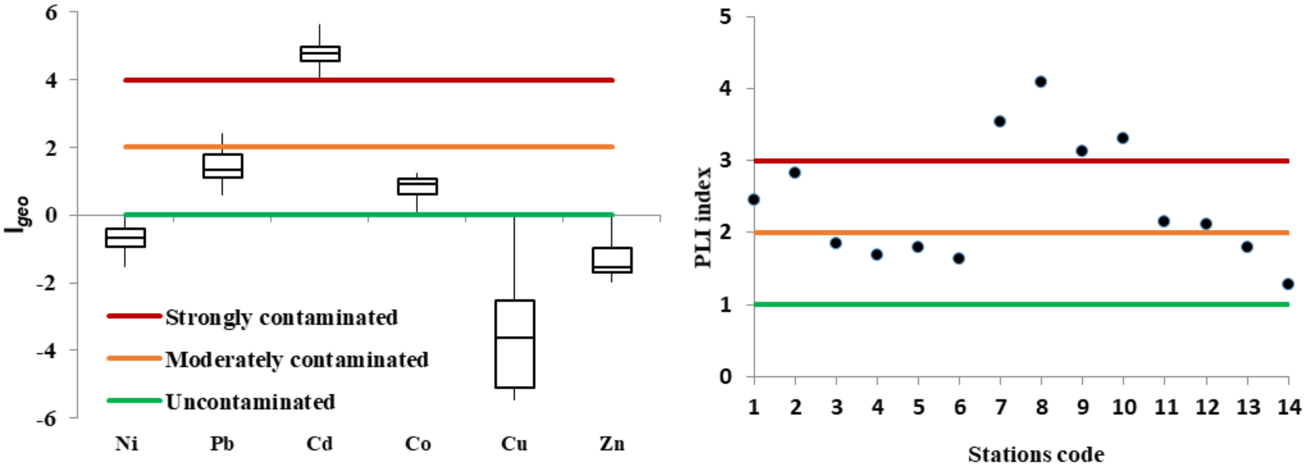


Fig. 4. Box and whisker plot for heavy metals in Suez Gulf sediment during the winter

The I_{geo} approach is often used as a standardization technique for assessing the extent of metal contamination in sedimentary environments. The negative values of Igeo ($I_{geo}< 0$) is seen at almost all sites suggesting the lack of Ni, Cu, and Zn contamination, as well as indicating a usually low presence of these heavy elements (Fig. 5a). Despite this, the amounts of Ni and Cu at Station 8 and Zn at Stations 2, 7, 9, 10, and 12 had Igeo values that ranged from 1.1 to 0, which means they were either not contaminated at all or very contaminated. The stations exhibiting a high frequency of $I_{geo}> 1$ for the heavy metals under investigation were identified as St.1, St.2, St.7, St.8, and St.9. This observation suggests a moderate amount of contamination, likely attributed to anthropogenic pollution. The study discovered a correlation between the pollution levels evaluated by the contamination factor (Cf) and the geo-accumulation index (I_{geo}). Igeo values ranging from 4.1 to 5.6 demonstrate a significant buildup of Cd in the data. These values show levels of contamination that are strong to very strong. The surface sediment samples collected from stations St.1 and St.2 had the highest Igeo values for Cd, measuring 5.2 and 5.6, respectively. These elevated values indicate a significant level of contamination, likely originating from human activities. Based on the Cf and I_{geo} indices, it was determined that Cd exhibited the most essential level of ecological danger, with Pb following closely after. Conversely, Co, Zn, Ni, and Cu were found to have the lowest environmental risk.



a b

Fig. 5. Ecological risk assessment of heavy metals in Suez Gulf sediment showing: **(a)** I_{geo}, and **(b)** PLI

DISCUSSION

The level of heavy metal pollution in seawater was evaluated by comparing the measured pollutant concentrations with China's criteria for seawater quality (GB 3097–1997, China) **(SEPA, 1997)** and the NOAA criteria **(Buchman, 2008)**. Based on the standards China set for seawater quality, it was seen that about 40% of seawater samples had Pb levels higher than the Class I ocean quality guideline for recreational use. Conversely, Cu concentrations in seawater were within the level specified by the Class I guideline across all stations. Nevertheless, it was noted that there was a surpassing of the Class I guideline for nickel (Ni) and zinc (Zn) in stations St.4 and St.5 in the summer and winter seasons, respectively. Additionally, there was an exceedance of the cadmium (Cd) guideline in Station 13 during the summer season, as shown in Fig. (2). Overall, the average yearly levels of Fe, Mn, Ni, Pb, Cd, Cu, and Zn were within the specified limits of Class I seawater quality guidelines. Consequently, the ecological danger associated with the presence of heavy metals in saltwater is deemed to be minimal.

However, using the National Oceanic and Atmospheric Administration's (NOAA) criteria to measure ecological risk shows that only the concentration of Fe in Station 5 during the summer months is higher than NOAA's long-term standard for Clean Coastal Waters (CCC). Similarly, in winter, Cu concentrations exceeded the CCC at Stations 4, 5, and 14 (Fig. 2). Consequently, our data suggest that the Suez Gulf exhibits a heightened worry about iron (Fe) and copper (Cu) presence. The higher amount of iron (Fe) in saltwater could be due to mineral weathering or pollution from people's actions **(Chakraborty & Owens, 2014)**. However, the average annual levels of iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), cadmium (Cd), copper (Cu), and zinc (Zn) were found to be less than what the National Oceanic and Atmospheric Administration (NOAA) says is safe for clean coastal waters. Based on an assessment of the adverse biological effects of these metals, they have not contaminated the water in the Gulf of Suez.

The average amount of Mn that was found was lower than what was found in studies from the South Australian coastline **(Chakraborty and Owens, 2014)**, the Red Sea **(Dar *et al.*, 2016)**, Zhanjiang Bay **(Zhang *et al.*, 2018)**, Jiuzhen Bay **(Sun *et al.*, 2020)**, and the Arabian Gulf **(Mahboob *et al.*, 2022)**. The slight disparity in lead content between the two investigations may be attributed to the inherent variability in geographical and temporal sampling. Still, human activities have little effect on the eastern shore of the Suez Gulf, specifically on the Sinai Peninsula side. This is mainly since few people live there **(Abo-El-Khair *et al.*, 2016)**. Therefore, conducting in-depth research on the heavy metal pollution along the Suez Gulf's western shore is crucial.

Station 8, functioning as a harbor for the shipment of ores, notably iron, had notably elevated concentrations of Fe, Mn, Ni, Pb, and Cu. **Dar *et al.* (2016)** discovered a connection between the transportation of ores and the presence of iron (Fe), manganese (Mn), nickel (Ni), and lead (Pb). The sediment at several locations within the Red Sea has been shown to have elevated concentrations of heavy metals. These metals are attributed to natural sources and human activities, including sewage discharge, industrial waste disposal, urban runoff, tourist-related operations, and shipping operations **(Nour & El-Sorogy, 2020)**. Stations 2 and 7 recorded the higher concentration of Pb due to resorts and chalets and the utilization of lead in the fuel of motor boats. These results agree with that of **Dar *et al.* (2016)** who attributed the presence of shipyard operations and fishing boats to the elevated concentration of lead (Pb) in the environment.

Moreover, it is significant to note that Station 2 had the highest levels of Cd and Zn, this finding might be due to the significant effect of local runoff from Suez City and the work of oil companies at the port. The elevated Zn levels may be ascribed to the substantial presence of antifouling paint with a high Zn content **(Dar *et al.*, 2016)**. According to **Attia and Ghrefat (2013)**, the paints used to protect ships and coastal structures from fouling and corrosion frequently contain copper (Cu), nickel (Ni), cadmium (Cd), and lead (Pb).

The current research conducts correlation analysis to examine the relationship between specific heavy metal concentrations in subsurface water and sedimentary stages. The results revealed substantial positive correlations in Cd content (R> 0.58, $P< 0.05$, N= 14), whereas significant negative correlations were seen in Zn (R= 0.63, $P< 0.05$, N= 14). The release of heavy metals from sediments into water may occur due to changes in hydrodynamics, temperature, and pH conditions, resulting in secondary pollution **(Li *et al.*, 2022)**. For the rest of the heavy metals, different geographic patterns were found between the sedimentary and aqueous phases along the western coast of the Gulf. Metal levels in sediments tend to rise slowly over time and are less likely to change quickly than metal levels in seawater. This means that sediment analysis is often a better indicator of long-term exposure to pollution. Additionally, the more significant proportion of metals present in sediment is likely attributed to the smaller particles, which possess a larger surface area **(Chakraborty & Owens, 2014)**. Therefore, the relationship between sediment types and the geographical distribution of heavy metals in sediment has been established **(Sun *et al.*, 2020)**.

Chakraborty and Owens (2014) conducted a study in which they noticed that the sediment sample with a particle size of less than 250μm exhibited the most significant quantities of total metals, regardless of the specific site from which the samples were collected. However, compared to seawater, sediments were found to contain higher quantities of metals, suggesting that sediments act as a reservoir for heavy metal contamination **(Sharifuzzaman *et al.*, 2016)**. Low remobilization rates into water or the presence of pathways that make it easier for metals to be removed from the water column could cause elevated concentrations of metals in sediments. Table (A.6) displays the average amounts of heavy metals in the sand samples collected from the Suez Gulf and other coastal regions. The average quantities of heavy metals were within the range of values in other coastal areas, except for Cd. The concentration of Cd observed in this study was found to be greater than the average amounts reported in the previous research included in Table (A.7). According to the study by **Nour and El-Sorogy (2020)**, the amounts of Ni, Pb, Cd, Cu, and Zn in sediments were higher than what was usually found at the Abu Zenima shoreline on the eastern coast of the Suez Gulf. This similarity in elevated levels of these elements in sediments suggests a resemblance to the composition of seawater.

The US National Oceanic and Atmospheric Administration has produced Sediment Quality Guidelines (SQGs) for assessing sediment quality based on pollutant concentrations. According to **Long *et al.* (1995)**, these guidelines draw from a chemical and biological effects database. Moreover, in the research of **Macdonald *et al.* (1996)**, the TEL represents the threshold at which adverse consequences are rarely expected. In contrast, the PEL signifies the concentration level at which unfavorable effects are projected to occur frequently.

In the current study, we compared the amounts of heavy metals detected in surface sediment samples to the background shale sedimentary rock's usual levels, as documented by **Turekian and Wedepohl (1961)**. Iron (Fe) and manganese (Mn) concentrations were much lower than the average background values in shale. These elements are of utmost importance and exhibit little toxicity towards marine species. Using elements such as Fe and Mn as sediment characteristics in a risk index is not advisable in this context, since their occurrence in sediments is primarily influenced by physical and chemical processes, which cannot be definitively associated with pollution **(Hakanson, 1980)**.

Nevertheless, it is essential to acknowledge that the single-variable contamination index has some limits since it is more appropriate for regions characterized by a solitary pollutant. Certain contaminants significantly impact specific geographical areas **(Yan *et al.*, 2016)**. To get a better idea of the overall pollution levels seen at several sample points, the pollutant load index (PLI) was calculated. Fig. (5b) depicts the geographical distributions of PLI values. The observed PLI values in the examined region; considered unpolluted, were lower than unity. The current research observed a range of PLI values from 1.3 to 4.1, with a mean value of 2.4. The contamination levels of the analyzed surface sediments varied, with St.8 having the highest contamination level, followed by St.7, St.10, and St.9. These stations exhibited severe pollution. On the other hand, St.2, St.1, St.11, and St.12 showed a contamination level of heavy pollution. Pollution Level Index (PLI) values in the remaining regions range from 1.3 to 1.9, indicating moderate pollution levels.

In the vicinity of the city of Suez, it was observed that both sewage and effluent were often released into the bay. This discharge was not limited to the city's waste but also included the waste generated by ships awaiting transit through the Suez Canal and by oil refineries, a fertilizer factory, and power plants. **Hamed *et al.* (2012)** also observed significant changes in the environmental conditions, particularly the water quality, on the western coasts of Suez Bay due to the fast industrial growth of south Suez City. Many sources convey a substantial volume of drainage water to the region. The effluents under consideration have an estimated volume of about 5.4 x 108 cubic meters per year, as reported in the **Suez Governorate (1998)** study. These effluents originate from several sources, including household sewage, sewage from oil refineries, fertilizer plants, power plants, textile manufacturers, and slaughterhouses. The wastes above are found to be polluted with a diverse range of species, including heavy metals, organic molecules, and non-organic entities. The Suez Gulf exhibits prevailing north-northwest winds consistently throughout the year, ranging from 6 to 9 knots. These winds give rise to a network of currents that run parallel to the Gulf's axis, with velocities ranging from 6 to 40cm/ sec **(Maillard, 1971)**. According to the research by **Miller and Ziegier (1965)**, the speed of the currents in the Suez Gulf separates sand particles and makes it harder for finer fractions to settle. The authors noted that these currents primarily influence the distribution of grain sizes in the sediment.

CONCLUSION

Based on the yearly averages, the evaluation of ecological risk suggests that the presence of heavy metals does not contaminate the water in the Suez Gulf. The Cf and I_{geo} indices, on the other hand, showed that Cd had the most critical ecological effects in seafloor sediment. Subsequently, Pb ranked second in environmental concern, while Co, Zn, Ni, and Cu demonstrated the slightest ecological danger. Based on the geographical distribution of the Pollution Load Index (PLI), the contamination levels observed in the research area varied from moderate pollution to severe pollution.

REFERENCES

Abo-El-Khair, E.M.; Fattah, L.M.A.; Abdel-Halim, A.M.; Abd-Elnaby, M.A.; Fahmy, M.A.; Ahdy, H.H.; Hemeilly, A.; El-Soud, A.A. and Shreadah, M.A. (2016)**.** Assessment of the Hydrochemical Characteristics of the Suez Gulf Coastal Waters during 2011-2013. J. Environ. Prot. (Irvine, Calif). 07: 1497–1521. https://doi.org/10.4236/jep.2016.711126

Algül, F. and Beyhan, M. (2020). Concentrations and sources of heavy metals in shallow sediments in Lake Bafa, Turkey. Sci. Rep. 10: 11782. https://doi.org/10.1038/s41598-020-68833-2.

Attia, O.E.A. and Ghrefat, H. (2013). Assessing heavy metal pollution in the recent bottom sediments of Mabahiss Bay, North Hurghada, Red Sea, Egypt. Env. Monit Assess 185: 9925–9934.

Buchman, M.F. (2008). NOAA screening quick reference Tables, NOAA OR and R Report 08-1. Seattle WA.

Chakraborty, S. and Owens, G. (2014). Metal distributions in seawater, sediment, and marine benthic macroalgae from the South Australian coastline. Int. J. Environ. Sci. Technol. 11: 1259–1270.

Chester, R.; Lin, F.J. and Basaham, A.S. (1994). Trace metal solid-state speciation changes associated with the down-column fluxes of oceanic particulates. J.- Geol. Soc. 151: 351–360. https://doi.org/10.1144/gsjgs.151.2.0351.

Dar, M.A.; Fouda, F.A.; El-Nagar, A.M. and Nasr, H.M. (2016). The effects of land-based activities on the near-shore environment of the Red Sea, Egypt. Environ. Earth Sci. 75: 188. https://doi.org/10.1007/s12665-015-4961-y.

Eaton, A.D.; Clescer, L.S. and Greenberg, A.E. (1995). Standard Methods for the Examination of Water and Wastewater, 19th Edition. Ed. American Public Health Association, Inc., New York.

Edokpayi, J.; Odiyo, J.; Popoola, O. and Msagati, T. (2016). Assessment of Trace Metals Contamination of Surface Water and Sediment: A Case Study of Mvudi River, South Africa. Sustainability 8: 135. https://doi.org/10.3390/su8020135.

Elgendy, A.R.; Soliman, F.A.; Dar, M.A.R.; Hassan, A.R.; Mohamedein, L.I. and Hassaan, M.A. (2018). Evaluation of some leachable heavy metals in the Seafloor sediments of the two navigation Harbours El Zaitiya and Adabiya, Gulf of Suez, Egypt. Egypt. J. Aquat. Biol. Fish. 22: 77–92. https://doi.org/10.21608/ejabf.2018.12299.

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

Hamed, M.A.; Mohamedein, L.I. and El-Sawy, M.A. (2012). Physiochemical analysis and speciation of heavy metals in wastewater and sediment samples from the Suez province in Egypt. J. Environ. Chem. Ecotoxicol. 4: 222–228.

Hossain, M.B.; Semme, S.A.; Ahmed, A.S.S.; Hossain, M.K.; Porag, G.S.; Parvin, A.; Shanta, T.B.; Senapathi, V. and Sekar, S. (2021). Contamination levels and ecological risk of heavy metals in sediments from the tidal river Halda, Bangladesh. Arab. J. Geosci. 14: 158. https://doi.org/10.1007/s12517-021-06477-w.

Li, F.; Yu, X.; Lv, J.; Wu, Q. and An, Y. (2022). Assessment of heavy metal pollution in surface sediments of the Chishui River Basin, China. PLoS One 17: e0260901. https://doi.org/10.1371/journal.pone.0260901.

Long, E.R.; Macdonald, D.D.; Smith, S.L. and Calder, F.D. (1995). Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environ. Manage. 19: 81–97. https://doi.org/10.1007/BF02472006.

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: 253–78. https://doi.org/10.1007/BF00118995.

Mahboob, S.; Ahmed, Z.; Farooq Khan, M.; Virik, P.; Al-Mulhm, N. and Baabbad, A.A.A. (2022). Assessment of heavy metals pollution in seawater and sediments in the Arabian Gulf, near Dammam, Saudi Arabia. J. King Saud Univ. Sci. 34: 101677. https://doi.org/10.1016/j.jksus.2021.101677.

Maillard, C. (1971). Étude hydrologique et dynamique de la Mer Rouge en hiver. Ann. lnst. Océanogr. 48: 113–140.

Miller, R.L. and Ziegier, J.M. (1965). A study of sediment distribution in the zone of shoaling waves over complicated bottom topography, in Miller, R.L. (Ed.), Deep Sea Research and Oceanographic Abstracts. Shepard Commemorative Volume, Macmillan, New York, N.Y., p. 1061. https://doi.org/10.1016/0011-7471(65)90997-6.

Nour, H.E. and El-Sorogy, A.S. (2020). Heavy metals contamination in seawater, sediments and seashells of the Gulf of Suez, Egypt. Environ. Earth Sci. 79: 274. https://doi.org/10.1007/s12665-020-08999-0.

Nour, H.E.; El-Sorogy, A.S.; Abd El-Wahab, M.; Nouh, E.S.; Mohamaden, M. and Al-Kahtany, K. (2019). Contamination and ecological risk assessment of heavy metals pollution from the Shalateen coastal sediments, Red Sea, Egypt. Mar. Pollut. Bull. 144: 167–172. https://doi.org/10.1016/j.marpolbul.2019.04.056.

Patel, P.; Raju, N.J.; Reddy, B.; Suresh, U.; Sankar, D.B. and Reddy, T.V.K. (2018). Heavy metal contamination in river water and sediments of the Swarnamukhi River Basin, India: risk assessment and environmental implications. Environ. Geochem. Health 40: 609–623. https://doi.org/10.1007/s10653-017-0006-7.

SEPA (State Environmental Protection Administration of China) (1997). The Seawater Quality Standard (GB3097-1997) (in Chinese), Beijing.

Sharifuzzaman, S.M.; Rahman, H.; Ashekuzzaman, S.M.; Islam, M.M.; Chowdhury, S.R. and Hossain, M.S. (2016). Heavy Metals Accumulation in Coastal Sediments, in Environmental Remediation Technologies for Metal-Contaminated Soils. Springer Japan, Tokyo, pp. 21–42. https://doi.org/10.1007/978-4-431-55759-3_2.

Suez Governorate (1998). The annual periodical Bulletin., n.d.

Sun, X.; Li, B.S.; Liu, X.L. and Li, C.X. (2020). Spatial Variations and Potential Risks of Heavy Metals in Seawater, Sediments, and Living Organisms in Jiuzhen Bay, China. J. Chem. 1–13. https://doi.org/10.1155/2020/7971294.

Turekian, K.K. and Wedepohl, K.H. (1961). Distribution of the elements in some major units of the earth’s crust. Bull. Geol. Soc. Am. 72: 175–192. https://doi.org/10.1130/0016-7606(1961)72[175:DOTEIS]2.0.CO;2.

Xu, G.; Liu, J.; Pei, S.; Hu, G. and Kong, X. (2015). Geochemical background and ecological risk of heavy metals in surface sediments from the west Zhoushan Fishing Ground of East China Sea. Environ. Sci. Pollut. Res. 22: 20283–20294. https://doi.org/10.1007/s11356-015-5662-5.

Yan, N.; Liu, W.; Xie, H.; Gao, L.; Han, Y.; Wang, M. and Li, H. (2016). Distribution and assessment of heavy metals in the surface sediment of Yellow River, China. J. Environ. Sci. 39: 45–51. https://doi.org/10.1016/j.jes.2015.10.017.

Zhang, J.; Zhou, F.; Chen, C.; Sun, X.; Shi, Y.; Zhao, H. and Chen, F. (2018). Spatial distribution and correlation characteristics of heavy metals in the seawater, suspended particulate matter and sediments in Zhanjiang Bay, China. PLoS One 13: e0201414.