Environmental Risk Assessment of Petroleum Activities in Surface Sediments, Suez Gulf, Egypt

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Abstract: The present study focuses on the risk assessment of heavy metal contamination in aquatic ecosystems by evaluating the current situation of heavy metals in seven locations (North Amer El Bahry, Amer, Bakr, Ras Gharib, July Water Floud, Ras Shokeir, and El Marageen) along the Suez Gulf coast that are well-known representative sites for petroleum activities in Egypt. One hundred and forty-six samples of surface sediments were carefully collected from twenty-seven profiles in the intertidal and surf zone. The hydrochemical parameters, such as pH and salinity (S‰), were measured during sample collection. The mineralogy study was carried out by an X-ray diffractometer (XRD), and the concentrations of Al, Mn, Fe, Cr, Cu, Co, Zn, Cd, and Pb were determined using inductively coupled plasma mass spectra (ICP-MS). The ecological risks of heavy metals were assessed by applying the contamination factor (CF), enrichment factor (EF), geoaccumulation index (Igeo), pollution load index (PLI), and potential ecological risk index (RI). The mineralogical composition mainly comprised quartz, dolomites, calcite, and feldspars. The average concentrations of the detected heavy metals, in descending order, were Al > Fe > Mn > Cr > Pb > Cu > Zn > Ni > Co > Cd. A non-significant or negative relationship between the heavy metal concentration in the samples and their textural grain size characteristics was observed. The coastal surface sediment samples of the Suez Gulf contained lower concentrations of heavy metals than those published for other regions in the world with petroleum activities, except for Al, Mn, and Cr. The results for the CF, EF, and Igeo showed that Cd and Pb have severe enrichment in surface sediment and are derived from anthropogenic sources, while Al, Mn, Fe, Cr, Co, Ni, Cu, and Zn originate from natural sources. By comparison, the PLI and RI results indicate that the North Amer El Bahry and July Water Floud are considered polluted areas due to their petroleum activities. The continuous monitoring and assessment of pollutants in the Suez Gulf will aid in the protection of the environment and the sustainability of resources.

Keywords: contamination factor; enrichment factor; geoaccumulation index; pollution load index; potential ecological risk index; heavy metals; Egypt

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1. Introduction

The increase in heavy metal concentrations in a coastal ecosystem is considered an indication of pollution in coastal zones. As a result, public health may be affected, and it can also be regarded as a threat to any sustainable development in coastal areas [1–7]. Metals in seawater and coastal sediments can easily enter the aquatic food chain [8–13]. In addition, heavy metals from natural and/or anthropogenic sources are among the most hazardous contaminants that affect the aquatic environment. The natural composition of the sediments can be further affected by human activities, such as discharging pollutants. Since pollutants are much higher and less variable in time and space than in seawater, marine sediments are favored for monitoring the environmental quality of seawater, and they represent the pollution level in the region in an integrated manner. Moreover, heavy metals from anthropogenic sources that enter the aquatic environment accumulate rapidly in the sediments, and they may represent a secondary source of heavy metals as time goes on. Sediments are heavy metal sources in marine environments, and they play a crucial role in their deposition and transmission through the trophic chain, so they must be controlled [7,14]. Due to their specific characteristics, sediments are well-known as the primary carriers of toxic metals. Coastal sediments have been found to be a reservoir for metal contaminants and to provide time-integrated records of contamination history in numerous studies. Investigating the heavy metals that accumulate in sediments allows for the continuous monitoring of pollutants in the environment, which can be differentiated from evaluating and researching the amount and form of contamination and making the necessary control decisions. Additionally, heavy metal pollution has become an important topic for research, especially, for tourism resources (beach sand, water, sea food, etc.) [15,16].

The Suez Gulf is an important strategic maritime region in Egypt because it joins the two world trade passages, the Suez Canal and the Red Sea. The majority of the Egyptian petroleum exploration and production processes are processed in the Suez Gulf. The northern part of the Suez Gulf coastal region is a densely industrialized zone with numerous tourism and entertainment projects. However, the northern region receives a large amount of wastewater from industrial and sewage effluents. Generally, the Suez Gulf has been subjected to point and nonpoint pollution sources as a result of oil industry wastes, oil spills, platforms, oil treatments, offshore oil, maritime traffics, housing projects, fertilizer manufacturing, power stations, domestic drainage, and microbial pollution, which has an effect on the health of these important marine habitats and, as a result, on their economic growth [17–19]. The monitoring and evaluation of chemical pollutants in the Suez Gulf are important steps to ensure that a healthy marine environment can coexist with required human activities. The tourism projects located in the northern part and near the mouth of the Suez Gulf require high environmental quality. Therefore, environmental monitoring and assessment programs are necessary continuously.

Petroleum exploration and production are a critical industry along the Suez Gulf coast. The Suez Gulf oil basin contains more than 1000 exploration wells, in more than 80 oil fields [20]. This industry is a point source of environmental pollution as it is heavily contaminated with heavy metals, which pose a high threat to the environment. The ecological risk assessment of heavy metals in coastal ecosystems is an important research area because of their potential toxicity and tendency to bioaccumulate and affect public health and seafood safety [21,22]. Moreover, water quality and coastal sediment pollutants in the Suez Gulf and the Red Sea are considered areas of research interest [9,18,19,23,24]. The area around Ras Gharib and Ras Shokeir is the oldest site of oil production. The oil wells in the study area are characterized by the production of a large volume of produced water. Water is applied to achieve maximum oil recovery by injecting it into the reservoir as an addition to the reservoir water. Thus, a large volume of wastewater is produced through the processes of oil treatment. The discharged water of the treatment processes is pumped through pipelines into the Suez Gulf water at 500 m from the coastal line. This water is highly saline water, with a salinity of 110‰, and it contains environmental pollutants, such as heavy metals [25–27]. There is a scarcity of studies on the environmental
impact of petroleum activities carried out at areas around Ras Gharib and Ras Shokeir to the best of the authors’ knowledge. Therefore, the present study aims to (1) assess the current situation of heavy metal concentrations and their spatial distribution along Suez Gulf coast’s surface sediments around Ras Gharib and Ras Shokeir; (2) characterize the texture and mineralogical composition of the surface sediments; (3) assess the ecological risk of heavy metals in the surface sediment by using the contamination factor (CF), enrichment factor (EF), geoaccumulation index ($I_{geo}$), pollution load index (PLI), and potential ecological risk index (RI) for nine heavy metals, namely, Mn, Fe, Cr, Co, Ni, Cu, Zn, Cd, and Pb.

2. Materials and Methods

2.1. The Study Area

The Suez Gulf occupies the Red Sea’s northwestern arm between the Eastern Desert and the Sinai Peninsula, Egypt. It was formed during the Red Sea rifting system. The Suez Gulf’s length, from the north (south Suez city), is about 314 km, and its width varies from 19 to 32 km. The average depth of the Suez Gulf ranges from 55 to 73 m. The study area exists between latitude 28°06′18″ and 28°44′25″ N, and longitude 33°18′45″ and 32°49′20″ E. It includes seven locations: North Amer El Bahry, Amer, Bakr, Ras Gharib, July Water Floud, Ras Shokeir, and El Marageen. These locations exist along the Suez Gulf western coast around Ras Gharib and Ras Shokeir (Figure 1).

![Figure 1. Map of the study area and measuring points.](image)

2.2. Sample Collection

The samples were collected in April 2014 from oil fields of North Amer El Bahry, Amer, Bakr, Ras Gharib, July Water Floud, Ras Shokeir, and El Marageen. The geographical data of each sample site (Figure 1) were located with a GPS (Garmin/eTrex Vista HCx/personal navigator) for 27 profiles (Table 1). The pH was directly measured in the field using a multi-parameter instrument (CRISON MM 40). Salinity ($S_\text{‰}$) was detected via a portable...
refractometer. One hundred and forty-six sediment samples were collected from 27 profiles that covered 7 locations along the Suez Gulf west coast (Figure 1 and Table 1). The sediments at each profile were collected from the intertidal zone and surf zone at a depth of 0.5 and 1.0 m, respectively. The collected sediment samples were put in sealable plastic bags, and then they were preserved in an isolated field box with ice to be transported to the laboratory. The sediments were air-dried at room temperature for three days and packed to be used for mechanical, mineralogical, and geochemical analysis.

All of the chemical analyses were carried out at the Environmental Geology Lab (EGL) and Environmental and Food Lab (EFL), University of Sadat City (ISO/IEC 17025/2017). Elements Al, Fe, Mn, Cr, Co, Ni, Cu, Zn, Cd, and Pb were measured with inductively coupled plasma mass spectra (ICAP TQ ICP-MS Thermo Fisher Scientific Inc., Waltham, MA, USA).

Grain size analysis was carried out using dry sieving. The mechanical data were processed using the GSSTAT program to determine the sediment texture classes. The mineralogy composition was identified using an X-ray diffractometer (D2 PHASER 2nd Gen/serial No. 209450/ BRUKER AXS—Germany) with a Ni filter using a Cu radiation wavelength of 1.542 Å at 30 Kv and 10 MA, a scan speed of 0.02 °/second, and 2θ from 10 to 70.

Sediment samples were ground using an agate mechanical mill (Retsch RM200). Twenty-seven sediment samples from the intertidal zone, 21 sediment samples from the surf zone at a 0.5 m depth, and 19 sediment samples at a 1 m depth were prepared to measure their metal concentration by acid digestion, according to the US EPA 3052 method [28], using the Speedwave microwave digestion system. The used reagents were deionized water, concentrated nitric acid, and concentrated hydrofluoric acid. The final volume was diluted to 50 mL. The present study adopted quality control by using standard sediment reference materials (GBW07333) provided by the Second Institute of Oceanography (SOA), China, and by duplicating sample or reference material. Experiment vessel contamination was avoided by pre-cleaning and soaking the used vessel in dilute nitric acid for at least 24 h, and then it was soaked and rinsed with deionized water. Blanks were prepared identically and by using the same reagents for testing the precision.

2.3. Environmental Pollution Indices

Ecological risk indices, such as CF, EF, Igeo, and PLI, were used to evaluate the degree of anthropogenic heavy metal contamination in surface sediments. The CF was calculated as the ratio of the measured concentration in the sediment to the background value [29]; that is, CF = sample metal concentration/baseline metal concentration, which is classified into four levels (Table 2).

The EF is an effective tool for assessing the sediment pollution degree (Table 2) to clarify whether the contamination is of natural or anthropogenic sources [30,31]. It was calculated by Equation (1).

\[ EF_x = \frac{(C_x/CAI)_{\text{sample}}}{(C_x/CAI)_{\text{background}}} \]  

where \((C_x/CAI)_{\text{sample}}\) is the ratio between the element \(x\) concentration in ppm and the analyzed sample’s aluminum concentration. \((C_x/CAI)_{\text{background}}\), the background, is the ratio between the element \(x\) concentration in ppm and the background reference metals [32]. The \(I_{\text{geo}}\) was used to assess metal contamination in sediments with a corresponding natural background (Table 2). Equation (2) was used to determine the geoaccumulation index according to Müller [33], as described by Boszke et al. [34].

\[ I_{\text{geo}} = \left( \frac{C_n}{1.5B_n} \right) \]  

where \(C_n\) = the measured concentration of heavy metals in the sediment. \(B_n\) = the geochemical background of an element. Factor 1.5 was used for the possible variations of the background data due to lithological variations.
Table 1. Field measurements, sampling, and hydrochemical properties.

| Location               | Name     | Profile NO. | Longitude E | Latitude N | Sample No. | H.T. –B.F. | B.F.- L.T. | Surf Zone | Surf Zone | pH    | Salinity (S‰) | 200 m * | 500 m * |
|------------------------|----------|-------------|-------------|------------|------------|------------|------------|-----------|-----------|-------|---------------|---------|---------|
| **North Amer El Bahry**| P1       | 32°49'18.408" | 28°44'25.080" | P1-1 to P1-6 | 6 | 2 | 28 | W1 | 8.22 | AMN 1 | 8.26 | 42 | 42 |
|                        | P2       | 32°49'20.460" | 28°44'22.668" | P2-1 to P2-5 | 3 | 3 | 18 | W2 | 8.23 | AMN 2 | pH 8.27 | 42 | 42 |
|                        | P3       | 32°49'21.648" | 28°44'19.680" | P3-1 to P3-5 | 3 | 2 | 28 | W3 | 8.24 | (5‰) | 42 | 42 |
|                        | P4       | 32°49'23.232" | 28°44'16.152" | P4-1 to P4-5 | 2 | 5 | 25.5 | W4 | 8.37 | (5‰) | 42 | 42 |
|                        | P5       | 32°49'24.168" | 28°44'12.588" | P5-1 to P5-5 | 4 | 4 | 10 | W5 | 8.4 | (5‰) | 42 | 42 |
| **Amer**               | P6       | 32°56'39.912" | 28°31'57.252" | P6-1 to P6-5 | 5 | 6 | 30 | W6 | 8.31 | AMS1 | 8.11 | 44 | 43 |
|                        | P7       | 32°56'40.848" | 28°31'54.948" | P7-1 to P7-5 | 5 | 4 | 16 | W7 | 8.3 | AMS2 | 8.12 | 44 | 43 |
|                        | P8       | 32°57'5.580"  | 28°31'30.468" | P8-1 to P8-12 | 10 | 1.2 | 6 | W8 | 8.19 | 43 | 42 | 43 |
|                        | P9       | 32°57'5.528"  | 28°30'59.508" | P9-1 to P9-10 | 6 | 2 | 10 | W9 | 8.4 | 44 | 43 | 43 |
|                        | P10      | 32°57'47.520" | 28°30'44.280" | P10-1 to P10-8 | 4 | 3 | 31 | W10 | 8.48 | 43 | 43 | 43 |
|                        | P11      | 32°58'38.388" | 28°29'38.888" | P11-1 to P11-8 | 10 | 4 | 19 | W11 | 8.38 | 42 | 42 | 42 |
| **Bakr**               | P12      | 32°59'55.608" | 28°29'19.320" | P12         |        |          |          | W12        | 8.23 | 44 | NB1 | 7.21 | 7.4 |
|                        | P13      | 32°59'55.140" | 28°29'6.180"  | P13-1 to P13-5 | 4 | 3 | 10 | W13 | 8.12 | 43 | 43 | 43 |
|                        | P14      | 33°0'31.788"  | 28°28'11.640" | P14-1 to P14-7 | 3.5 | 3.5 | 11 | W14 | 8.13 | 43 | 43 | 43 |
|                        | P15      | 33°0'34.500"  | 28°26'59.172" | P15-1 to P15-3 | 5 | 3 | 3 | W15 | 7.49 | 44 | 43 | 43 |
|                        | P16      | 33°0'32.520"  | 28°24'6.048"  | P16-1 to P16-6 | 3 | 4 | 25 | W16 | 7.11 | 43 | 43 | 43 |
| **Gharib**             | P17      | 33°3'56.088"  | 28°23'13.128" | P17-1 to P17-5 | 6 | 4 | 10 | W17 | 7.31 | 43 | GH1 | 7.42 | 7.49 |
|                        | P18      | 33°3'48.888"  | 28°22'48.900" | P18-1 to P18-6 | 4.5 | 3.5 | 7 | W18 | 7.41 | 42 | 43 | 43 |
|                        | P19      | 33°3'6.572"   | 28°21'39.908" | P19-1 to P19-3 | 2 | 1 | N.M. | W19 | 7.44 | 43 | 43 | 43 |
| **July Water Floud**   | P20      | 33°3'12.600"  | 28°11'12.372" | P20-1 to P20-6 | 6 | 2 | 45 | W20 | 7.89 | 43 | JWF 1 | 7.81 | 7.71 |
|                        | P21      | 33°3'14.612"  | 28°10'17.652" | P21-1 to P21-6 | 3 | 2 | 10 | W21 | 7.83 | 43 | JWF 2 | 7.82 | 43 |
|                        | P22      | 33°3'14.048"  | 28°8'52.692"  | P22-1 to P22-6 | 5 | 2 | 14.5 | W22 | 7.97 | 43 | 43 | 43 |
| **Ras Shokeir**        | P23      | 33°3'15.42.048" | 28°8'22.668" | P23-1 to P23-5 | 5 | 5 | 13 | W23 | 7.56 | SH1 | 7.88 | 43 |
|                        | P24      | 33°3'16.500"  | 28°7'44.760"  | P24-1 to P24-3 | 2.5 | 2.5 | N.M. | W24 | 7.64 | SH2 | 7.88 | 43 |
|                        | P25      | 33°3'16.58.368" | 28°7'40.080" | P25-1 to P25-2 | 4 | 5 | 9.5 | W25 | 7.57 | 43 | 43 | 43 |
|                        | P26      | 33°3'16.500"  | 28°6'13.680"  | P26-1 to P26-4 | 3 | 3 | N.M. | W26 | 7.92 | 43 | 43 | 43 |
| **El Marageen**        | P27      | 33°3'18.45.900" | 28°6'1.080" | P27-1 to P27-3 | 3 | 3 | N.M. | W27 | 7.79 | M1 | 7.78 | 42 |

*Distance from shoreline; H.T.: high tide; B.F.: beach face; L.T.: low tide; N.M.: not measured.
The PLI was applied to compare the integrated pollution status at different locations. The PLI was calculated as the nth root of the multiplications of CF (Equation (3)) for all elements at each profile [35,36]. The PLI for each area was calculated as the nth root of the multiplications of PLI for the intertidal and surf zone at 0.5 and 1 m.

\[
\text{PLI} = (\text{CF}_1 \times \text{CF}_2 \times \text{CF}_3 \times \ldots \times \text{CF}_n)^{1/n}
\]  

(3)

The RI was used to assess the ecological risk (Table 2) of heavy metals in sediments [37,38]. It considers four factors: concentration, type of pollutant, toxicity level, and the sensitivity of the water body to metal contamination in sediments. The potential ecological risk index was calculated by Equation (4).

\[
\text{RI} = \sum \text{Er}, \text{Er} = \text{Tr} \times \text{CF}
\]  

(4)

where Er is the potential ecological risk factor of the individual element, and Tr is the toxic response [37,39].

Statistical analysis was used to analyze the results of grain size and heavy metals in the sediment samples. Pearson correlation analysis was applied to process the data and to identify the sources of heavy metal contamination of the sediments [24]. The statistical analyses were carried out using SPSS 20.0 (IBM, Armonk, NY, USA).

Table 2. Contamination factor (CF), enrichment factor (EF), geoaccumulation index ($I_{geo}$), pollution load index (PLI), and risk index (RI) classes describing the degree of metal concentration in sediment.

| Index | Index Categories | Description | Reference |
|-------|------------------|-------------|-----------|
| CF    | $\leq 1$         | Low CF      | [35]      |
|       | $1 < \text{CF} \leq 3$ | Moderate CF |           |
|       | $3 < \text{CF} \leq 6$ | Considerable CF | |
|       | $6 < \text{CF}$ | Very high   |           |
| EF    | $<1$             | No enrichment |         |
|       | $1–3$            | Minor enrichment | [40]     |
|       | $3–5$            | Moderate enrichment | |
|       | $5–10$           | Moderately severe enrichment | |
|       | $10–25$          | Severe enrichment |           |
|       | $25–50$          | Very severe enrichment |         |
|       | $>50$            | Extremely severe enrichment |       |
| $I_{geo}$ | $0 \leq I_{geo} \leq 1$ | Unpolluted | [33] |
|       | $0 < I_{geo} \leq 1$ | Unpolluted to moderately polluted |        |
|       | $1 < I_{geo} \leq 2$ | Moderately polluted |         |
|       | $2 < I_{geo} \leq 3$ | Moderately to strongly polluted |        |
|       | $3 < I_{geo} \leq 4$ | Strongly polluted |           |
|       | $4 < I_{geo} \leq 5$ | Strongly to extremely polluted |         |
|       | $5 < I_{geo}$ | Extremely polluted |           |
| PLI   | $1 > \text{PLI}$ | Unpolluted | [36] |
|       | $1 < \text{PLI}$ | Polluted    |           |
| RI    | $\text{RI} < 40$ | Low ecological risk | [37] |
|       | $40 < \text{RI} < 80$ | Moderate ecological risk |       |
|       | $80 < \text{RI} < 160$ | Appreciable ecological risk |       |
|       | $160 < \text{RI} < 320$ | High ecological risk |         |
|       | $320 < \text{RI}$ | Serious ecological risk |          |

3. Results
3.1. Sediment Properties

Grain size analysis results is illustrated in Table 3. The sediments of the present study area at the intertidal and surf zones were mainly gravelly sand. The intertidal zone’s sorting varies from well to moderately sorted sediments in the rest of the study area. In contrast, the surf zone sediments are mainly poorly sorted. The mineralogical compositions of the coastal sediment at the study area mainly comprised quartz, feldspars, aragonite, and calcite (Figure 2).
Table 3. Sediment types and concentrations of heavy metals in ppm, except for aluminum and iron, which are in %.

| Location       | Profile No. | Sediment Type | Gravel % | Sand % | Silt % | Al  | Fe   | Mn   | Cr   | Co   | Ni   | Cu   | Zn   | Cd   | Pb   |
|----------------|-------------|---------------|----------|--------|--------|-----|------|------|------|------|------|------|------|------|------|
| North Amer     | P1          | Gravel        | 53.16    | 46.84  | 0.00   | 2.8 | 0.7  | 323.9| 93.4 | 3.7  | 26.2 | 46.5 | 27.8 | 2.6  | 463.3|
| El Bahry      | P2          | Sand          | 9.94     | 90.03  | 0.03   | 9.6 | 2.8  | 768.4| 247.2| 9.9  | 41.2 | 16.6 | 45.3 | 4.0  | 246.9|
| Amer          | P3          | Sand          | 0.52     | 99.38  | 0.10   | 4.1 | 1.3  | 386.0| 72.8 | 4.9  | 13.7 | 80.3 | 56.6 | 6.2  | 613.6|
|               | P4          | Sand          | 9.79     | 90.05  | 0.16   | 3.5 | 0.5  | 210.2| 50.0 | 1.8  | 4.9  | 49.2 | 25.6 | 1.0  | 376.4|
|               | P5          | Sand          | 3.84     | 96.15  | 0.01   | 4.6 | 0.2  | 119.5| 38.8 | 1.0  | 5.0  | 40.6 | 16.6 | 0.1  | 252.5|
| Amer          | P6          | Gravelly sed. | 14.87    | 85.06  | 0.07   | 4.8 | 0.3  | 145.8| 39.2 | 1.2  | 4.2  | 36.9 | 16.8 | 0.5  | 486.4|
| Bakr          | P7          | Sand          | 0.27     | 99.71  | 0.02   | 9.2 | 1.2  | 447.4| 116.4| 5.7  | 2.8  | 13.2 | 71.1 | 2.3  | 956.4|
|               | P8          | Gravel        | 60.19    | 39.81  | 0.00   | 5.2 | 0.4  | 147.6| 35.4 | 2.3  | 3.7  | 42.3 | 45.2 | 0.9  | 345.0|
|               | P9          | Sand          | 0.47     | 99.46  | 0.07   | 1.4 | 0.2  | 118.8| 43.0 | 1.1  | 84.0 | 0.1  | 2.9  | 3.0  | 232.3|
|               | P10         | Gravelly sed. | 34.82    | 64.99  | 0.19   | 1.7 | 0.1  | 46.5 | 10.1 | 0.8  | 7.1  | 26.6 | 20.1 | 0.4  | 669.7|
|               | P11         | Sand          | 2.51     | 97.34  | 0.15   | 3.0 | 1.9  | 225.3| 124.7| 6.6  | 11.7 | 69.5 | 75.7 | 0.6  | 294.3|
| Bakr          | P12         | Gravelly sed. | 34.22    | 65.78  | 0.00   | 6.3 | 0.5  | 38.8 | 20.0 | 0.6  | 5.2  | 19.5 | 25.2 | 0.4  | 293.7|
|               | P13         | Sand          | 5.33     | 94.64  | 0.03   | 0.5 | 0.1  | 30.0 | 4.3  | 0.4  | 9.9  | 80.0 | 4.2  | 10.8 | 4.5  | 312.6|
|               | P14         | Gravelly sed. | 25.55    | 74.45  | 0.00   | 1.3 | 0.1  | 7.5  | 3.1  | 0.2  | 7.9  | 6.8  | 5.3  | 0.1  | 27.2 |
|               | P15         | Gravelly sed. | 14.96    | 85.01  | 0.03   | 0.9 | 0.4  | 94.5 | 41.5 | 1.4  | 83.4 | 19.5 | 11.7 | 2.9  | 7.3  |
|               | P16         | Gravelly sed. | 25.81    | 74.19  | 0.00   | 2.2 | 0.2  | 26.5 | 8.1  | 0.3  | 8.5  | 6.3  | 0.1  | 320.9|
| Gharib        | P17         | Gravelly sed. | 19.99    | 79.95  | 0.06   | 9.3 | 1.4  | 178.0| 85.7 | 2.9  | 9.1  | 143.9| 50.1 | 1.0  | 108.6|
|               | P18         | Gravelly sed. | 19.99    | 79.95  | 0.06   | 10.9| 0.5  | 66.3 | 58.3 | 1.6  | 4.1  | 28.5 | 12.9 | 2.7  | 224.6|
|               | P19         | Gravelly sed. | 21.55    | 78.45  | 0.00   | 8.4 | 0.9  | 115.3| 112.5| 2.1  | 5.1  | 34.3 | 25.5 | 1.6  | 205.5|
| July Water     | P20         | Gravelly sed. | 26.21    | 73.76  | 0.03   | 12.5| 0.8  | 101.0| 134.0| 5.3  | 5.9  | 54.4 | 22.5 | 2.0  | 430.9|
| Floud         | P21         | Sand          | 4.65     | 95.32  | 0.03   | 5.7 | 0.3  | 169.8| 36.7 | 2.7  | 4.2  | 40.0 | 60.1 | 0.8  | 932.0|
|               | P22         | Sand          | 0.28     | 99.72  | 0.00   | 7.7 | 0.8  | 392.2| 146.9| 7.8  | 6.4  | 170.1| 143.8| 2.2  | 541.2|
| Ras Shokeir    | P23         | Gravelly sed. | 45.40    | 54.60  | 0.00   | 0.2 | 0.0  | 11.5 | 4.5  | 0.1  | 7.7  | 0.3  | 0.2  | 0.6  | 40.1 |
|               | P24         | Gravelly sed. | 10.63    | 89.37  | 0.00   | 6.6 | 0.6  | 110.1| 916.8| 2.8  | 3.8  | 80.5 | 34.5 | 2.6  | 591.4|
|               | P25         | Sand          | 4.81     | 95.18  | 0.01   | 4.8 | 0.3  | 66.6 | 294.6| 0.6  | 5.8  | 13.1 | 12.4 | 0.2  | 148.8|
|               | P26         | Gravelly sed. | 22.10    | 75.25  | 2.70   | 1.3 | 0.2  | 39.7 | 17.7 | 0.5  | 7.3  | 6.7  | 3.2  | 0.4  | 30.2 |
| El Marageen   | P27         | Sand          | 0.04     | 99.87  | 0.09   | 0.2 | 0.1  | 58.2 | 95.4 | 0.3  | 2.9  | 10.2 | 34.4 | 0.3  | 11.2 |
Table 3. Cont.

| Location       | Profile No. | Sediment type | Gravel % | Sand % | Silt % | Al  | Fe   | Mn   | Cr   | Co   | Ni   | Cu   | Zn   | Cd   | Pb   |
|----------------|-------------|---------------|----------|--------|--------|-----|------|------|------|------|------|------|------|------|------|
| North Amer      |             |               |          |        |        |     |      |      |      |      |      |      |      |      |      |
| El Bahry       | P1          | Gravelly sed. | 36.73    | 63.15  | 0.12   | 1.2 | 0.5  | 131.2| 27.6 | 1.5  | 5.2  | 22.8 | 18.8 | 0.4  | 118.0|
|                | P2          | Gravelly sed. | 16.98    | 82.74  | 0.28   | 1.6 | 0.4  | 176.9| 30.2 | 1.3  | 5.2  | 34.8 | 37.6 | 4.3  | 230.3|
|                | P3          | Gravelly sed. | 20.33    | 79.14  | 0.53   | 4.3 | 1.4  | 399.6| 75.4 | 5.0  | 14.2 | 83.1 | 58.6 | 6.4  | 635.1|
|                | P4          | Gravel        | 54.78    | 45.18  | 0.04   | 3.9 | 0.1  | 118.7| 38.7 | 1.0  | 10.1 | 40.4 | 13.0 | 0.4  | 214.4|
|                | P5          | Gravelly sed. | 16.30    | 83.28  | 0.42   | 3.7 | 0.5  | 135.3| 36.5 | 1.2  | 3.6  | 36.1 | 36.1 | 7.1  | 145.6|
| Amer           |             |               |          |        |        |     |      |      |      |      |      |      |      |      |      |
|                | P6          | Gravelly sed. | 10.91    | 88.87  | 0.22   | 4.9 | 1.2  | 187.6| 56.9 | 2.9  | 8.3  | 82.9 | 388.8| 7.2  | 486.4|
|                | P7          | Gravelly sed. | 38.93    | 61.05  | 0.02   | 2.9 | 1.4  | 325.8| 87.1 | 5.0  | 80.2 | 24.3 | 56.5 | 4.2  | 654.4|
|                | P8          | Gravelly sed. | 26.30    | 73.34  | 0.36   | 1.4 | 0.6  | 354.4| 15.2 | 4.4  | 8.8  | 14.2 | 587.1| 2.2  | 639.9|
| Bakr           |             |               |          |        |        |     |      |      |      |      |      |      |      |      |      |
|                | P9          | Sand          | 6.99     | 92.46  | 0.55   | 0.9 | 0.1  | 29.1 | 12.2 | 0.4  | 87.1 | 3.4  | 16.1 | 2.5  | 173.4|
|                | P10         | Gravelly sed. | 23.87    | 75.35  | 0.78   | 0.4 | 0.0  | 8.2  | 2.6  | 0.1  | 8.3  | 0.3  | 1.8  | 0.4  | 105.7|
|                | P11         | Sand          | 5.29     | 94.56  | 0.15   | 0.2 | 0.0  | 4.3  | 1.1  | 0.1  | 8.5  | 0.8  | 1.5  | 0.2  | 7.0  |
| Gharib         |             |               |          |        |        |     |      |      |      |      |      |      |      |      |      |
|                | P13         | Gravelly sed. | 34.14    | 65.86  | 0      | 1.7 | 0.3  | 62.8 | 31.4 | 1.3  | 16.1 | 68.9 | 34.0 | 0.5  | 301.2|
| July Water      |             |               |          |        |        |     |      |      |      |      |      |      |      |      |      |
| Floud          | P20         | Gravelly sed. | 34.08    | 65.69  | 0.23   | 7.6 | 5.9  | 832.8| 258.0| 10.1 | 24.1 | 263.4| 66.4 | 6.3  | 130.4|
|                | P21         | Gravelly sed. | 23.6     | 76.40  | 0      | 1.7 | 5.1  | 915.3| 404.5| 12.0 | 43.0 | 684.7| 195.4| 2.2  | 114.7|
| Ras Shokeir    |             |               |          |        |        |     |      |      |      |      |      |      |      |      |      |
|                | P23         | Gravelly sed. | 14.98    | 84.99  | 0.03   | 9.8 | 2.9  | 1943.9| 265.2| 11.6 | 47.1 | 308.2| 218.0| 9.3  | 351.3|
|                | P24         | Sand          | 2.44     | 96.99  | 0.57   | 0.6 | 0.4  | 115.8| 377.4| 2.0  | 79.8 | 10.3 | 12.6 | 1.1  | 28.8|
Table 3. Cont.

| Location     | Profile No | Sediment type | Gravel % | Sand % | Silt % | Al  | Fe   | Mn   | Cr   | Co   | Ni   | Cu   | Zn   | Cd   | Pb   |
|--------------|------------|---------------|----------|--------|--------|-----|------|------|------|------|------|------|------|------|------|
| North Amer   | P1         | Sand          | 1.99     | 98.01  | 0.00   | 1.3 | 4.9  | 1350.9| 284.5| 14.9 | 53.3 | 235.3| 194.0| 4.6  | 121.6|
| El Bahry     | P2         | Sand          | 0.00     | 99.41  | 0.59   | 3.7 | 0.6  | 331.1 | 68.1 | 2.6  | 9.9  | 59.4 | 38.0 | 1.0  | 328.4|
|              | P3         | Gravel        | 72.86    | 24.71  | 2.43   | 2.0 | 0.9  | 338.1 | 63.7 | 3.0  | 8.1  | 63.8 | 74.7 | 1.8  | 207.0|
|              | P4         | Sand          | 0.00     | 98.80  | 1.20   | 4.0 | 1.5  | 1210.8| 394.4| 10.4 | 103.2| 412.4| 132.4| 4.1  | 218.7|
|              | P5         | Gravelly sed. | 14.00    | 85.25  | 0.75   | 3.2 | 1.2  | 1645.2| 269.1| 10.1 | 25.3 | 537.2| 173.2| 5.0  | 347.6|
| Amer         | P6         | Sand          | 4.01     | 95.56  | 0.43   | 4.9 | 8.2  | 4533.5| 604.0| 29.4 | 47.1 | 617.2| 231.3| 4.9  | 993.0|
|              | P7         | Gravelly sed. | 36.59    | 60.09  | 3.32   | 3.2 | 0.6  | 204.7 | 33.0 | 2.0  | 77.0 | 45.0 | 184.7| 2.9  | 165.8|
|              | P8         | Gravelly sed. | 17.00    | 83.00  | 0.00   | 2.1 | 0.8  | 255.7 | 219.5| 10.5 | 22.9 | 77.4 | 61.4 | 0.3  | 153.0|
|              | P9         | Sand          | 2.54     | 96.84  | 0.62   | 5.8 | 0.5  | 216.5 | 53.6 | 3.1  | 1.9  | 123.4| 117.3| 0.6  | 428.4|
|              | P10        | Sand          | 0.29     | 97.48  | 2.23   | 3.5 | 0.2  | 119.0 | 28.6 | 2.0  | 81.6 | 7.6  | 4.3  | 4.0  | 520.8|
|              | P11        | Sand          | 0.01     | 99.64  | 0.35   | 1.1 | 0.1  | 46.4  | 10.3 | 0.9  | 84.2 | 5.9  | 98.7 | 2.6  | 181.5|
| Bakr         | P13        | Gravelly sed. | 31.75    | 68.25  | 0.00   | 1.5 | 0.1  | 45.5  | 5.4  | 0.8  | 84.8 | 0.3  | 10.2 | 4.0  | 214.6|
|              | P14        | Gravelly sed. | 30.71    | 69.29  | 0.00   | 1.5 | 0.1  | 6.9   | 2.8  | 0.2  | 7.4  | 4.3  | 1.0  | 0.3  | 27.4 |
|              | P16        | Gravelly sed. | 28.24    | 71.50  | 0.26   | 8.4 | 7.1  | 800.2 | 340.4| 12.6 | 44.9 | 579.5| 396.8| 5.3  | 552.8|
| Gharib       | P18        | Gravelly sed. | 32.82    | 66.15  | 1.03   | 1.6 | 1.6  | 219.7 | 116.7| 2.2  | 2.7  | 72.1 | 34.5 | 0.8  | 192.6|
| July Water   | P19        | Gravelly sed. | 28.51    | 71.21  | 0.28   | 3.3 | 2.3  | 1036.5| 181.8| 16.2 | 14.4 | 242.2| 234.1| 3.3  | 1652.6|
| Floud        | P20        | Gravelly sed. | 16.52    | 83.48  | 0.00   | 1.2 | 9.6  | 2769.6| 8002.5| 20.7 | 86.3 | 410.8| 247.5| 12.8 | 404.2|
| Ras Shokeir  | P21        | Gravel        | 0.28     | 99.72  | 0.00   | 1.5 | 10.4 | 651.2 | 4596.3| 30.7 | 189.6| 495.2| 961.0| 43.6 | 260.2|
|              | P22        | Sand          | 89.28    | 10.72  | 0.00   | 1.5 | 0.1  | 19.9  | 27.4 | 0.2  | 7.5  | 1.7  | 1.6  | 0.2  | 30.1 |
3.2. Hydrochemical Properties

Table 1 shows the sample and profile locations and the hydrochemical parameters, such as pH and salinity (S‰), for the seven studied locations. The pH values varied from an average of 7.39 at Ras Gharib to 8.34 at Amer. The pH decreased from north to south at the surf zone. It also decreased from north to south at 200 and 500 m distances from the shoreline. The average salinity increased from 42‰ in the north to 43.5‰ in the south. In sum, pH showed a decrease from north to south, whereas S‰ showed an increase at the same direction.

3.3. Heavy Metals

Table 3 presents the concentration of heavy metals in the intertidal and surf zone sediment samples. The average of iron concentration at the intertidal zone varied from 0.1% at El Marageen to 9.5% at Ras Gharib, whereas manganese was from 39.5 ppm at Bakr to 361.6 ppm at North Amer El Bahry. The average of chromium concentration ranged from 15.4 ppm at Baker to 257.9 ppm at Ras Shokeir, whereas the average of cobalt concentration was from 0.3 ppm at El Marageen to 5.3 ppm at July Water Floud. The average of nickel concentration had a minimum value (2.9 ppm) at El Marageen, while its maximum average (35.3 ppm) was recorded at Bakr. The minimum average of copper was 10.2 ppm at El Marageen, and the maximum average was 88.1 ppm at July Water Floud. The average zinc concentration varied from 11.9 ppm at Baker to 75.5 ppm at July Water Floud; the average of cadmium concentration was from 0.3 ppm at El Marageen to 2.8 ppm at North Amer El Bahry. Finally, the average of lead concentration ranged from 8.2 ppm at El Marageen to 634.7 ppm at July Water Floud.

The heavy metals average for the surf zone at 0.5 m had minimum values for Mn, Cr, Co, and Ni at Ras Gharib. The minimum value for Cd was at Bakr, and for Fe, Cu, Zn, and Pb, it was at Ras Shokeir. The maximum average value for Fe, Co, and Cu was at July Water Floud; for Mn, Cr, Ni, and Cd, it was at Ras Shokeir; for Zn, it was at Amer; and for Pb, it was at Baker.

Figure 2. XRD patterns of some sediment samples.
The Pearson correlations matrix (Table 4) shows a non-significant and negative relation between heavy metals and grain size for the surface sediments at the intertidal and surf zones. The correlation matrix displays a strong significant positive relation between metal pairs Co, Fe, and Zn ($\geq 0.5$), as well as between Cu and Zn at the intertidal zone. There is a strong positive correlation between heavy metal pairs Fe, Mn, Cr, Co, Ni, Cu, and Zn at the surf zone.

### 3.4. Ecological Indices

The CF average (Table 5) at the intertidal zone for the study localities ranged from low to moderate with respect to Al, Mn, Fe, Cr, Co, Ni, Cu, and Zn. The EF (Table 6) for Mn, Fe, Cr, Co, Ni, Cu, and Zn revealed no enrichment to minor or moderate enrichment for the study area at the intertidal zone, except at North Amer El Bahry, Baker, July Water Floud, and El Marageen. The EF of Zn showed considerable enrichment in Cd and Pb. North Amer El Bahry, Baker, July Water Floud, and El Marageen showed considerable enrichment in Zn, Cd, and Pb at the surf zone. The $I_{geo}$ average as shown in Table 6 was calculated to relate the metal contamination in sediments to its natural origin.

The pollution load index (PLI) and the potential ecology risk index (RI) averages (Table 6) were calculated to detect and classify the polluted localities. The PLI average ranged from 0.18 at El Marageen to 1.09 at July Water Floud. The North Amer El Bahry and July Water Floud at intertidal zone are classified as polluted localities. At the surf zone, the PLI indicated North Amer El Bahry and July Water Floud as polluted areas, in addition to Amer (1.05).

The RI average (Table 6) reflects serious ecological risk due to the presence of Cd and Pb, which are potential environmental toxic metals. Figures 3–5 show the spatial distribution of the pollution load index and the potential ecological risk index of the above-mentioned metals.

![Figure 3](image-url)  
**Figure 3.** Spatial distribution for the pollution load index (PLI) and the potential ecological risk index (RI) at North Amer El-Bahry.
### Table 4. Pearson correlation coefficient variables of heavy metals in surface sediments.

#### Intertidal Zone

|        | Gravel % | Sand % | Silt % | Al    | Fe    | Mn    | Cr    | Co    | Ni    | Cu    | Zn    | Cd    | Pb    |
|--------|----------|--------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Gravel % | 1        |        |        |       |       |       |       |       |       |       |       |       |       |
| Sand %  | −1.00    | 1      |        |       |       |       |       |       |       |       |       |       |       |
| Silt %  | 0.03     | −0.06  | 1      |       |       |       |       |       |       |       |       |       |       |
| Al      | −0.05    | 0.06   | −0.22  | 1     |       |       |       |       |       |       |       |       |       |
| Fe      | −0.21    | 0.21   | −0.11  | 0.53  | 1     |       |       |       |       |       |       |       |       |
| Mn      | −0.30    | 0.30   | −0.09  | 0.17  | 0.43  | 1     |       |       |       |       |       |       |       |
| Cr      | −0.19    | 0.20   | −0.12  | 0.29  | 0.24  | 0.05  | 1     |       |       |       |       |       |       |
| Co      | −0.24    | 0.24   | −0.15  | 0.57  | 0.86  | 0.43  | 0.26  | 1     |       |       |       |       |       |
| Ni      | −0.17    | 0.17   | −0.07  | 0.32  | 0.02  | −0.05 | −0.11 | 0.01  | 1     |       |       |       |       |
| Cu      | −0.16    | 0.16   | −0.15  | 0.42  | 0.35  | 0.22  | 0.27  | 0.49  | −0.26 | 1     |       |       |       |
| Zn      | −0.35    | 0.35   | −0.18  | 0.36  | 0.47  | 0.49  | 0.15  | 0.70  | −0.24 | 0.74  | 1     |       |       |
| Cd      | −0.22    | 0.23   | −0.16  | 0.19  | 0.42  | 0.14  | 0.19  | 0.48  | 0.55  | 0.13  | 0.15  | 1     |       |
| Pb      | −0.13    | 0.14   | −0.22  | 0.34  | 0.15  | 0.09  | 0.19  | 0.40  | −0.21 | 0.24  | 0.45  | 0.26  | 1     |

#### Surf Zone at 0.5 m depth

|        | Gravel % | Sand % | Silt % | Al    | Fe    | Mn    | Cr    | Co    | Ni    | Cu    | Zn    | Cd    | Pb    |
|--------|----------|--------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Gravel % | 1        |        |        |       |       |       |       |       |       |       |       |       |       |
| Sand %  | −1.00    | 1      |        |       |       |       |       |       |       |       |       |       |       |
| Silt %  | −0.28    | 0.26   | 1      |       |       |       |       |       |       |       |       |       |       |
| Al      | −0.04    | 0.04   | −0.12  | 1     |       |       |       |       |       |       |       |       |       |
| Fe      | −0.12    | 0.12   | −0.03  | 0.25  | 1     |       |       |       |       |       |       |       |       |
| Mn      | −0.14    | 0.14   | −0.20  | 0.66  | 0.68  | 1     |       |       |       |       |       |       |       |
| Cr      | −0.27    | 0.27   | 0.19   | 0.30  | 0.71  | 0.65  | 1     |       |       |       |       |       |       |
| Co      | −0.21    | 0.21   | 0.12   | 0.69  | 0.61  | 0.76  | 0.72  | 1     |       |       |       |       |       |
| Ni      | −0.24    | 0.24   | 0.00   | 0.09  | 0.02  | 0.19  | 0.39  | 0.24  | 1     |       |       |       |       |
| Cu      | −0.10    | 0.10   | −0.02  | 0.47  | 0.50  | 0.64  | 0.68  | 0.83  | 0.18  | 1     |       |       |       |
| Zn      | −0.16    | 0.16   | −0.01  | 0.28  | 0.02  | 0.19  | −0.03 | 0.22  | −0.18 | 0.16  | 1     |       |       |
| Cd      | −0.37    | 0.37   | 0.28   | 0.79  | 0.15  | 0.41  | 0.28  | 0.73  | 0.13  | 0.45  | 0.38  | 1     |       |
| Pb      | 0.15     | −0.15  | −0.06  | 0.07  | 0.40  | 0.30  | 0.03  | 0.14  | −0.04 | −0.12 | 0.27  | 0.05  | 1     |
### Table 4. Cont.

#### Surf Zone at 1.0 m depth

|        | Gravel % | Sand % | Silt % | Al  | Fe   | Mn   | Cr   | Co   | Ni   | Cu   | Zn   | Cd   | Pb   |
|--------|----------|--------|--------|-----|------|------|------|------|------|------|------|------|------|
| Gravel % | 1        |        |        | 1   |      |      |      |      |      |      |      |      |      |
| Sand %  | −1.00    | 1      |        |      |      |      |      |      |      |      |      |      |      |
| Silt %  | 0.17     | −0.21  | 1      |      |      |      |      |      |      |      |      |      |      |
| Al      | −0.20    | 0.19   | 0.13   | 1   |      |      |      |      |      |      |      |      |      |
| Fe      | −0.27    | 0.28   | −0.34  | 0.13| 1    |      |      |      |      |      |      |      |      |
| Mn      | −0.29    | 0.29   | −0.19  | 0.19| 0.66 | 1    |      |      |      |      |      |      |      |
| Cr      | −0.17    | 0.18   | −0.27  | −0.25| 0.74 | 0.41 | 1    |      |      |      |      |      |      |
| Co      | −0.38    | 0.39   | −0.34  | 0.12| 0.90 | 0.75 | 0.59 | 1    |      |      |      |      |      |
| Ni      | −0.42    | 0.42   | 0.00   | −0.17| 0.51 | 0.12 | 0.52 | 0.48 | 1    |      |      |      |      |
| Cu      | −0.34    | 0.35   | −0.24  | 0.46 | 0.78 | 0.75 | 0.41 | 0.82 | 0.33 | 1    |      |      |      |
| Zn      | −0.28    | 0.28   | −0.20  | 0.11 | 0.78 | 0.24 | 0.54 | 0.76 | 0.68 | 0.64 | 1    |      |      |
| Cd      | −0.27    | 0.28   | −0.20  | −0.17| 0.71 | 0.15 | 0.65 | 0.67 | 0.80 | 0.47 | 0.92 | 1    |      |
| Pb      | −0.17    | 0.17   | −0.07  | 0.40 | 0.26 | 0.46 | 0.02 | 0.45 | −0.10| 0.38 | 0.18 | 0.01 | 1    |
Table 5. Contamination factor (CF) results of metals in sediment samples.

| Location          | Profile No. | Intertidal zone |
|-------------------|-------------|-----------------|
|                   |             | Al  | Mn  | Fe  | Cr  | Co  | Ni  | Cu  | Zn  | Cd  | Pb  |
| North Amer      | P1          | 0.34 | 0.54 | 0.20 | 1.10 | 0.52 | 1.86 | 0.39 | 26.97 | 28.95 | 28.95 |
| El Bahry        | P2          | 1.20 | 1.28 | 0.80 | 2.91 | 0.82 | 0.66 | 0.64 | 40.52 | 15.43 | 15.43 |
| P3               | 0.51        | 0.64 | 0.38 | 0.86 | 0.27 | 3.21 | 0.80 | 0.36 | 10.39 | 23.53 | 23.53 |
| P4               | 0.44        | 0.35 | 0.13 | 0.59 | 0.10 | 1.97 | 0.36 | 10.39 | 23.53 | 23.53 |
| P5               | 0.57        | 0.20 | 0.06 | 0.46 | 0.10 | 1.62 | 0.23 | 0.63 | 15.78 | 15.78 |
| Amer             | P6          | 0.60 | 0.24 | 0.09 | 0.46 | 0.08 | 1.48 | 0.24 | 5.08  | 30.40 | 30.40 |
| P7               | 1.15        | 0.75 | 0.33 | 1.37 | 0.06 | 0.53 | 1.00 | 23.92 | 59.78 | 59.78 |
| P8               | 0.65        | 0.25 | 0.11 | 0.42 | 0.07 | 1.69 | 0.64 | 9.13  | 21.56 | 21.56 |
| P9               | 0.18        | 0.20 | 0.06 | 0.51 | 1.68 | 0.00 | 0.04 | 30.51 | 14.52 | 14.52 |
| P10              | 0.21        | 0.08 | 0.03 | 0.12 | 0.14 | 1.06 | 0.28 | 3.82  | 41.86 | 41.86 |
| P11              | 0.38        | 0.38 | 0.54 | 1.47 | 0.23 | 2.78 | 1.07 | 6.31  | 18.39 | 18.39 |
| Bakr             | P12         | 0.78 | 0.06 | 0.13 | 0.24 | 0.10 | 0.78 | 0.36 | 3.68  | 18.36 | 18.36 |
| P13              | 0.06        | 0.05 | 0.02 | 0.05 | 1.60 | 0.17 | 0.15 | 45.82 | 19.54 | 19.54 |
| P14              | 0.16        | 0.01 | 0.02 | 0.04 | 0.16 | 0.27 | 0.07 | 1.40  | 1.70  | 1.70  |
| P15              | 0.11        | 0.16 | 0.11 | 0.49 | 1.67 | 0.78 | 0.16 | 29.29 | 0.45  | 0.45  |
| P16              | 0.28        | 0.04 | 0.05 | 0.10 | 0.00 | 0.34 | 0.09 | 1.06  | 20.06 | 20.06 |
| Gharib           | P17         | 1.35 | 0.11 | 0.14 | 0.69 | 0.08 | 1.14 | 0.18 | 27.41 | 14.04 | 14.04 |
| P18              | 1.04        | 0.19 | 0.25 | 1.32 | 0.10 | 1.37 | 0.36 | 16.56 | 12.85 | 12.85 |
| P19              | 1.15        | 0.30 | 0.39 | 1.01 | 0.18 | 5.76 | 0.71 | 9.73  | 6.78  | 6.78  |
| July Water Floud | P20         | 1.56 | 0.17 | 0.23 | 1.58 | 0.12 | 2.17 | 0.32 | 20.68 | 26.93 | 26.93 |
| P21              | 0.71        | 0.28 | 0.10 | 0.43 | 0.08 | 1.60 | 0.85 | 8.40  | 58.25 | 58.25 |
| P22              | 0.95        | 0.65 | 0.22 | 1.73 | 0.13 | 6.80 | 2.02 | 22.26 | 33.82 | 33.82 |
| Ras Shokeir      | P23         | 0.02 | 0.02 | 0.01 | 0.05 | 0.15 | 0.01 | 0.00 | 5.72  | 2.51  | 2.51  |
| P24              | 0.81        | 0.18 | 0.17 | 10.79 | 0.08 | 3.22 | 0.49 | 26.97 | 36.96 | 36.96 |
| P25              | 0.59        | 0.11 | 0.08 | 3.47 | 0.12 | 0.52 | 0.17 | 1.53  | 9.30  | 9.30  |
| P26              | 0.16        | 0.07 | 0.06 | 0.21 | 0.15 | 0.27 | 0.05 | 3.56  | 1.89  | 1.89  |
| El Marageen      | P27         | 0.39 | 2.40 | 0.13 | 0.66 | 0.03 | 2.00 | 0.89 | 8.26  | 8.26  | 8.26  |
Table 5. Cont.

| Location         | Profile No. |     |    |    |    |    |    |    |    |    |
|------------------|-------------|-----|----|----|----|----|----|----|----|----|
|                  |             | Al  | Mn | Fe | Cr | Co | Ni | Cu | Zn | Cd |
| North Amer El Bahry |             |     |    |    |    |    |    |    |    |    |
| P1               |             | 0.15| 0.22| 0.14| 0.33| 0.09| 0.10| 0.91| 0.27| 4.53| 7.38|
| P2               |             | 0.20| 0.29| 0.12| 0.36| 0.08| 0.10| 1.39| 0.53| 43.38| 14.40|
| P3               |             | 0.53| 0.67| 0.39| 0.89| 0.30| 0.28| 3.32| 0.82| 65.33| 39.69|
| P4               |             | 0.49| 0.20| 0.04| 0.45| 0.06| 0.20| 1.62| 0.18| 4.07| 13.40|
| P5               |             | 0.46| 0.23| 0.13| 0.43| 0.07| 0.07| 1.45| 7.69| 72.26| 9.10|
| P6               |             | 0.61| 0.31| 0.34| 0.67| 0.17| 0.17| 3.32| 5.48| 73.92| 30.40|
| P7               |             | 0.36| 0.54| 0.40| 1.02| 0.29| 1.60| 0.97| 0.80| 43.27| 40.90|
| P8               |             | 0.17| 0.59| 0.18| 0.18| 0.26| 0.18| 0.57| 8.27| 22.39| 39.99|
| P9               |             | 0.11| 0.05| 0.02| 0.14| 0.02| 1.74| 0.14| 0.23| 25.41| 10.84|
| P10              |             | 0.05| 0.01| 0.00| 0.03| 0.00| 0.17| 0.01| 0.03| 3.68 | 6.61 |
| P11              |             | 0.03| 0.01| 0.00| 0.01| 0.00| 0.17| 0.03| 0.02| 2.42 | 0.44 |
| Amer             |             |     |    |    |    |    |    |    |    |    |    |
| P13              |             | 0.22| 0.10| 0.08| 0.37| 0.08| 0.32| 2.75| 0.48| 5.47 | 18.83|
| P14              |             | 0.19| 0.01| 0.02| 0.03| 0.01| 0.15| 0.17| 0.01| 3.34 | 1.73 |
| P16              |             | 0.13| 1.77| 3.02| 4.12| 4.30| 0.23| 3.41| 0.93| 9.81 | 51.29|
| Bakr             |             |     |    |    |    |    |    |    |    |    |    |
| P17              |             | 0.16| 0.13| 0.28| 2.16| 0.11| 0.22| 1.31| 0.32| 13.30| 15.59|
| P18              |             | 0.13| 0.14| 0.19| 0.85| 0.13| 0.18| 2.86| 1.01| 29.94| 23.26|
| Gharib           |             |     |    |    |    |    |    |    |    |    |    |
| P20              |             | 0.94| 1.39| 1.68| 3.04| 0.59| 0.48| 10.54| 0.93| 64.37| 8.15 |
| P21              |             | 0.22| 1.53| 1.47| 4.76| 0.70| 0.86| 27.39| 2.75| 22.64| 7.17 |
| P22              |             | 0.94| 0.97| 0.74| 3.31| 1.02| 0.71| 14.77| 2.76| 191.03| 7.51 |
| July Water Floud |             |     |    |    |    |    |    |    |    |    |    |
| P23              |             | 1.22| 3.24| 0.82| 3.12| 0.68| 0.94| 12.33| 3.07| 94.79| 21.96|
| P26              |             | 0.07| 0.19| 0.10| 4.44| 0.12| 1.60| 0.41| 0.18| 11.43| 1.80 |
| Location                  | Profile No. | Al  | Mn  | Fe  | Cr  | Co  | Ni  | Cu  | Zn  | Cd  | Pb  |
|---------------------------|-------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| **North Amer El Bahry**   |             |     |     |     |     |     |     |     |     |     |     |
| P1                        | 0.16        | 2.25| 1.41| 3.35| 0.88| 1.07| 9.41| 2.73| 46.63| 7.60|     |
| P2                        | 0.46        | 0.55| 0.16| 0.80| 0.15| 0.20| 2.37| 0.53| 9.80 | 20.52|     |
| P3                        | 0.25        | 0.56| 0.26| 0.75| 0.18| 0.16| 2.55| 1.05| 18.29| 12.94|     |
| P4                        | 0.50        | 2.02| 0.41| 4.64| 0.61| 2.06| 16.50| 1.86| 41.52| 13.67|     |
| P5                        | 0.40        | 2.74| 0.35| 3.17| 0.59| 0.51| 21.49| 2.44| 50.50| 21.72|     |
| **Amer**                  |             |     |     |     |     |     |     |     |     |     |     |
| P6                        | 0.60        | 7.56| 2.33| 7.11| 1.73| 0.94| 24.69| 3.26| 49.61| 62.06|     |
| P7                        | 0.40        | 0.34| 0.17| 0.39| 0.12| 1.54| 1.80| 2.60| 29.29| 10.36|     |
| P8                        | 0.26        | 0.43| 0.23| 2.58| 0.62| 0.46| 3.10| 0.86| 2.55 | 9.56  |     |
| P9                        | 0.72        | 0.36| 0.14| 0.63| 0.18| 0.04| 4.94| 1.65| 5.85 | 26.27 |     |
| P10                       | 0.43        | 0.20| 0.05| 0.34| 0.12| 1.63| 0.30| 0.06| 40.71| 32.55|     |
| P11                       | 0.14        | 0.08| 0.02| 0.12| 0.05| 1.68| 0.24| 1.39| 26.73| 11.34|     |
| **Bakr**                  |             |     |     |     |     |     |     |     |     |     |     |
| P13                       | 0.19        | 0.08| 0.02| 0.06| 0.04| 1.70| 0.01| 0.14| 40.71| 13.41|     |
| P14                       | 0.19        | 0.01| 0.02| 0.03| 0.01| 0.15| 0.17| 0.01| 3.31 | 1.71  |     |
| P16                       | 1.04        | 1.33| 2.02| 4.00| 0.74| 0.90| 23.18| 5.59| 53.55| 34.55|     |
| **Gharib**                |             |     |     |     |     |     |     |     |     |     |     |
| P18                       | 0.20        | 0.37| 0.46| 1.37| 0.13| 0.05| 2.89| 0.49| 8.27 | 12.04 |     |
| **July Water Floud**      |             |     |     |     |     |     |     |     |     |     |     |
| P20                       | 0.40        | 1.73| 0.66| 2.14| 0.95| 0.29| 9.69| 3.30| 33.96| 103.29|     |
| P21                       | 0.15        | 4.62| 2.74| 94.15| 1.22| 1.73| 16.43| 3.49| 130.42| 25.26|     |
| P22                       | 0.18        | 1.09| 2.98| 54.07| 1.81| 3.79| 19.81| 13.54| 444.39| 16.26|     |
| **Ras Shokeir**           |             |     |     |     |     |     |     |     |     |     |     |
| P23                       | 0.19        | 0.03| 0.01| 0.32| 0.01| 0.15| 0.07| 0.02| 1.79 | 1.88  |     |
| Location        | Profile No. | (EF)   | (I_geo) | PLI   | PLI Average | RI | RI Average |
|----------------|-------------|--------|---------|-------|-------------|----|------------|
| North Amer El Bahry | P1          | 1.57   | 0.58    | 3.20  | 0.62        | 1.53 | 5.40       |
|                | P2          | 1.07   | 0.67    | 2.43  | 0.49        | 0.69 | 0.55       |
|                | P3          | 1.26   | 0.74    | 1.67  | 0.56        | 0.54 | 0.67       |
|                | P4          | 0.80   | 0.30    | 1.34  | 0.23        | 0.22 | 0.47       |
|                | P5          | 0.35   | 0.10    | 0.80  | 0.10        | 0.18 | 2.85       |
|                | P8          | 0.41   | 0.15    | 0.77  | 0.12        | 0.14 | 2.46       |
|                | P7          | 0.65   | 0.29    | 1.20  | 0.29        | 0.05 | 0.46       |
|                | P3           | 0.38   | 0.16    | 0.64  | 0.21        | 0.11 | 2.59       |
|                | P13         | 1.11   | 0.36    | 0.36  | 0.36        | 0.93 | 2.02       |
|                | P30         | 0.36   | 0.15    | 0.56  | 0.22        | 0.66 | 4.99       |
|                | P11         | 0.99   | 1.42    | 0.88  | 1.03        | 0.63 | 7.35       |
|                | P10         | 0.47   | 0.30    | 1.22  | 0.10        | 0.10 | 1.32       |
|                | P19         | 0.26   | 0.34    | 0.88  | 0.15        | 0.16 | 5.00       |
|                | P17         | 0.11   | 0.08    | 0.71  | 0.48        | 0.13 | 7.13       |
|                | P16         | 0.16   | 0.19    | 0.35  | 0.06        | 0.01 | 1.23       |
|                | P18         | 0.08   | 0.11    | 0.52  | 0.07        | 0.06 | 0.84       |
|                | P15         | 0.19   | 0.24    | 0.12  | 0.10        | 0.10 | 1.32       |
|                | P14         | 0.26   | 0.34    | 0.88  | 0.15        | 0.16 | 5.00       |
|                | P20         | 0.11   | 0.15    | 0.10  | 0.07        | 0.06 | 0.84       |
|                | P21         | 0.40   | 0.14    | 0.61  | 0.22        | 0.12 | 2.25       |
|                | P12         | 0.69   | 0.23    | 1.81  | 0.48        | 0.13 | 7.13       |
|                | P23         | 0.90   | 0.39    | 2.49  | 0.38        | 7.25 | 0.60       |
|                | P22         | 0.19   | 0.13    | 0.85  | 0.53        | 0.13 | 7.13       |
|                | P24         | 0.26   | 0.34    | 0.88  | 0.15        | 0.16 | 5.00       |
|                | P21         | 0.11   | 0.15    | 0.10  | 0.07        | 0.06 | 0.84       |
|                | P19         | 0.26   | 0.34    | 0.88  | 0.15        | 0.16 | 5.00       |
|                | P18         | 0.08   | 0.11    | 0.52  | 0.07        | 0.06 | 0.84       |
|                | P15         | 0.19   | 0.24    | 0.12  | 0.10        | 0.10 | 1.32       |
|                | P14         | 0.26   | 0.34    | 0.88  | 0.15        | 0.16 | 5.00       |
|                | P20         | 0.11   | 0.15    | 0.10  | 0.07        | 0.06 | 0.84       |
|                | P21         | 0.40   | 0.14    | 0.61  | 0.22        | 0.12 | 2.25       |
|                | P12         | 0.69   | 0.23    | 1.81  | 0.48        | 0.13 | 7.13       |
|                | P23         | 0.90   | 0.39    | 2.49  | 0.38        | 7.25 | 0.60       |
|                | P22         | 0.19   | 0.13    | 0.85  | 0.53        | 0.13 | 7.13       |
|                | P24         | 0.26   | 0.34    | 0.88  | 0.15        | 0.16 | 5.00       |
|                | P21         | 0.11   | 0.15    | 0.10  | 0.07        | 0.06 | 0.84       |
|                | P19         | 0.26   | 0.34    | 0.88  | 0.15        | 0.16 | 5.00       |
|                | P18         | 0.08   | 0.11    | 0.52  | 0.07        | 0.06 | 0.84       |
|                | P15         | 0.19   | 0.24    | 0.12  | 0.10        | 0.10 | 1.32       |
|                | P14         | 0.26   | 0.34    | 0.88  | 0.15        | 0.16 | 5.00       |
|                | P20         | 0.11   | 0.15    | 0.10  | 0.07        | 0.06 | 0.84       |
|                | P21         | 0.40   | 0.14    | 0.61  | 0.22        | 0.12 | 2.25       |
|                | P12         | 0.69   | 0.23    | 1.81  | 0.48        | 0.13 | 7.13       |
|                | P23         | 0.90   | 0.39    | 2.49  | 0.38        | 7.25 | 0.60       |
|                | P22         | 0.19   | 0.13    | 0.85  | 0.53        | 0.13 | 7.13       |
|                | P24         | 0.26   | 0.34    | 0.88  | 0.15        | 0.16 | 5.00       |
|                | P21         | 0.11   | 0.15    | 0.10  | 0.07        | 0.06 | 0.84       |
|                | P19         | 0.26   | 0.34    | 0.88  | 0.15        | 0.16 | 5.00       |
|                | P18         | 0.08   | 0.11    | 0.52  | 0.07        | 0.06 | 0.84       |
|                | P15         | 0.19   | 0.24    | 0.12  | 0.10        | 0.10 | 1.32       |
|                | P14         | 0.26   | 0.34    | 0.88  | 0.15        | 0.16 | 5.00       |
|                | P20         | 0.11   | 0.15    | 0.10  | 0.07        | 0.06 | 0.84       |
|                | P21         | 0.40   | 0.14    | 0.61  | 0.22        | 0.12 | 2.25       |
|                | P12         | 0.69   | 0.23    | 1.81  | 0.48        | 0.13 | 7.13       |
|                | P23         | 0.90   | 0.39    | 2.49  | 0.38        | 7.25 | 0.60       |
|                | P22         | 0.19   | 0.13    | 0.85  | 0.53        | 0.13 | 7.13       |
|                | P24         | 0.26   | 0.34    | 0.88  | 0.15        | 0.16 | 5.00       |

Table 6. Enrichment factor (EF), geoaccumulation index (I_geo), pollution load index (PLI), and risk index (RI) results of metals in sediment samples.
### Location Profile

#### Gharib

| No. | Mn | Fe | Co | Cr | Ni | Cu | Zn | Cd | Pb | Al | Mn | Fe | Cr | Co | Ni | Cu | Zn | Cd | Pb |
|-----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| P17 | 0.78 | 1.71 | 13.25 | 0.65 | 1.33 | 8.04 | 19.89 | 81.61 | 95.71 | -3.20 | -3.56 | -2.43 | 0.53 | -3.82 | -2.80 | -0.20 | -2.21 | 3.15 | 3.38 |
| P18 | 1.05 | 1.43 | 6.49 | 1.02 | 1.36 | 21.94 | 77.13 | 229.38 | 178.19 | -2.52 | -2.46 | -3.00 | -0.82 | -3.50 | -3.08 | 0.93 | -0.58 | 4.32 | 3.95 |

#### July Water Flood

| No. | Mn | Fe | Co | Cr | Ni | Cu | Zn | Cd | Pb | Al | Mn | Fe | Cr | Co | Ni | Cu | Zn | Cd | Pb |
|-----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| P20 | 1.48 | 1.78 | 3.23 | 0.63 | 0.51 | 31.20 | 9.94 | 68.42 | 8.66 | -0.67 | -0.11 | 0.16 | 1.02 | -1.34 | -1.64 | 2.81 | -0.68 | 5.42 | 2.44 |
| P21 | 7.05 | 6.78 | 22.00 | 3.26 | 3.97 | 126.62 | 127.24 | 104.69 | 33.13 | -2.79 | 0.02 | -0.03 | 1.67 | -1.09 | -0.80 | 4.19 | 0.88 | 3.92 | 2.26 |
| P22 | 1.03 | 0.79 | 3.52 | 1.08 | 0.76 | 15.73 | 29.40 | 203.39 | 7.99 | -0.68 | -0.63 | -1.02 | 1.14 | -0.56 | -1.07 | 3.30 | 0.88 | 6.99 | 2.32 |

#### Ras

| No. | Mn | Fe | Co | Cr | Ni | Cu | Zn | Cd | Pb | Al | Mn | Fe | Cr | Co | Ni | Cu | Zn | Cd | Pb |
|-----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| P23 | 2.66 | 0.67 | 2.57 | 0.56 | 0.78 | 10.14 | 25.25 | 77.94 | 18.05 | -0.30 | 1.11 | -0.87 | 1.06 | -1.13 | -0.67 | 3.04 | 1.03 | 5.98 | 3.87 |

### Surf Zone at 0.5 m depth

#### Location Profile

| Location | Profile No. | (EF) | (d_{geo}) | PLI | PLI Average | RI | RI Average |
|----------|-------------|------|-----------|-----|-------------|----|------------|
| Gharib | P17 | 1.46 | 0.97 | 21.50 | 5.64 | 6.84 | 60.44 | 175.47 | 299.44 | 48.79 | -3.27 | 0.59 | -0.09 | 1.16 | -0.77 | -0.49 | 2.65 | 0.87 | 4.96 | 2.34 |
| P18 | 1.20 | 0.36 | 1.74 | 0.33 | 0.43 | 5.15 | 11.58 | 21.23 | 44.47 | -1.70 | -1.44 | -3.18 | -0.91 | -3.30 | -2.92 | 0.66 | -1.49 | 2.71 | 0.87 |

### Surf Zone at 1.0 m depth

#### Location Profile

| Location | Profile No. | (EF) | (d_{geo}) | PLI | PLI Average | RI | RI Average |
|----------|-------------|------|-----------|-----|-------------|----|------------|
| Ras | P23 | 12.51 | 3.86 | 11.76 | 2.87 | 1.56 | 40.87 | 53.92 | 82.13 | 102.74 | -1.31 | 2.33 | 0.64 | 2.24 | 0.21 | -0.67 | 4.04 | 1.12 | 5.05 | 5.37 |

### Table 6. Cont.
## 4. Discussion

Grain size analysis contributes to evaluating the environment’s textural and depositional characteristics. The particle size distribution in sediments is mostly controlled by the parent materials’ particle sizes and depositional processes [41]. Generally, the distribution of grain size in the study area may reflect the action of erosion and accretion processes along the coast, as well as the influence of shell fragments and the dominance of terrigenous fine and coarse grain-sized sediments [42]. Furthermore, the distance from the shoreline and water depth represents the main factors that control grain size distributions [43].

The morphological and sedimentological characteristics of the beach area represent an accretional area (Tables 1 and 3). This area is divided into two main zones: the first has a high accretion rate that is characterized by relatively finer and moderately sorted sediments with gentle slope beach face; the second zone is characterized by relatively low accretional processes of less sorted and coarser sediment with a relatively steep beach face [44].

The carbonate content in the sediment of the studied stations is mainly attributable to their biogenic origin containing coral reefs and marine shells as well as land-derived terrigenous materials rich in carbonate [42]. The average pH and salinity recorded agreed with the results of previous studies and international reports [19]. The fluctuation of pH and salinity may be attributed to local climatic change and human activities, such as
producing water discharge and internal current circulations along the gulf. The pH and salinity data revealed that the Suez Gulf’s water is located within the acceptable levels of the seawater quality standard.

Heavy metal concentration averages at the intertidal zone along the seven locations were as follows: Fe > Pb > Mn > Cr > Cu > Zn > Ni > Co > Cd in descending order. The Fe concentrations in the studied sediments were relatively high, indicating natural contamination by sediment of terrigenous origin. The average of heavy metals for the surf zone at 0.5 m along the seven areas was as follows: Fe > Mn > Pb > Cr > Zn > Cu > Ni > Co > Cd in decreasing order, whereas the heavy metals average for the surf zone at 1 m along the seven areas in descending order was as follows: Fe > Mn > Cr > Pb > Cu > Zn > Ni > Co > Cd. The heavy metals average along the study area in descending order was as follows: Al > Fe > Mn > Cr > Pb > Cu > Zn > Ni > Co > Cd. The variation in the concentration of these metals may result from the differences in the particle size distribution, percentage of silicates, oxide-hydroxide, carbonates, and organic matters in sediments [45]. Upon comparing the findings of this study with those of a previous one from coastal areas associated with the oil industry in other areas of the world, it can be concluded that the total average concentrations of Fe, Co, Ni, Cu, Zn, Cd, and Pb of the surface sediments along the intertidal and surf zones were equal to or lower than those in other areas of the world. However, the total average concentrations of Al, Mn, and Cr were higher than those in other localities (Table 7).

![Figure 5: Spatial distribution for the pollution load index (PLI) and the potential ecological risk index (RI) at Ras Shokeir.](image-url)
Table 7. Comparison of heavy metal averages in surface sediment of the present study and other coastal areas with presence of the petroleum industry.

| Region                          | Al (%) | Fe (%) | Mn     | Cr     | Co     | Ni     | Cu     | Zn     | Cd     | Pb     | Reference |
|---------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-----------|
| Intertidal                      | 4.7    | 0.6    | 210.2  | 103.8  | 2.5    | 15.9   | 39.7   | 33.1   | 1.6    | 332.0  | Present study |
| Surf 0.5 m                       | 2.8    | 1.7    | 359.4  | 124.3  | 4.2    | 24.9   | 106.8  | 124.2  | 3.8    | 282.2  | [46]      |
| Surf 1.0 m                       | 2.9    | 2.7    | 831.6  | 805.4  | 9.1    | 50.1   | 210.0  | 168.2  | 5.4    | 368.4  | [47]      |
| Average                         | 3.5    | 1.7    | 467.0  | 344.0  | 5.3    | 30.3   | 118.8  | 108.5  | 3.6    | 327.5  | [48]      |
| Gulf of Suze                    | -      | 0.5    | 434.0  | -      | 6.7    | 19.0   | 15.0   | 25.3   | 0.9    | 24.0   | [49]      |
| Red Sea                         | -      | 0.5    | 245.0  | -      | 6.0    | 27.0   | 33.0   | 40.0   | 1.1    | 15.2   | [50]      |
| Ras Gharib                      | -      | -      | -      | -      | -      | 6.3    | 0.1    | 6.8    | 0.1    | 1.0    | [51]      |
| Red Sea                         | -      | 0.3    | 382.9  | -      | -      | -      | 7.7    | -      | 3.3    | 47.8   | [52]      |
| Shalatein, Red Sea              | -      | -      | -      | -      | -      | 14.8   | 0.7    | 51.3   | 0.4    | 3.5    | [53]      |
| Ras Gharib                      | -      | 0.4    | 137.8  | -      | 13.7   | 21.5   | 24.1   | 30.1   | 3.5    | 39.4   | [54]      |
| Red sea                         | -      | 1.1    | 277.4  | -      | 15.6   | 32.0   | 41.3   | 58.4   | 3.5    | 46.7   | [55]      |
| Red Sea                         | -      | 2.0    | 547.5  | -      | -      | -      | 63.0   | 97.5   | 3.9    | 42.0   | [56]      |
| Gulf of Suze                    | -      | 0.03   | 70.7   | -      | -      | 15.3   | -      | 1.3    | 18.0   | 11.4   | [57]      |
| Shalatein, Red Sea              | -      | 0.9    | 198.8  | -      | 3.9    | 17.5   | 9.4    | 44.2   | 0.5    | 11.4   | [58]      |
| Al-Khobar—Arabian Gulf, Saudi Arabia | 0.2 | 0.8    | 116.1  | 50.9   | 4.5    | 75.9   | -      | 180.1  | 0.2    | 5.2    | [59]      |
| Southern Gulf of Mexico         | -      | -      | -      | 16.7   | -      | 17.7   | 20.9   | 6.5    | -      | 3.8    | [60]      |
| Brazil (America)                | -      | 2.6    | 422.0  | 34.5   | -      | 17.1   | 46.3   | 28.0   | 0.7    | 20.2   | [61]      |
| North Sea (Europe)              | -      | -      | 232.0  | -      | 68.8   | 242.0  | 3,350.0| 7.0    | 2,393.0| 23.5   | [62]      |
| Black Sea (Europe)              | -      | 2.6    | 166.5  | 68.0   | 36.1   | 72.5   | 38.8   | 90.0   | 2.0    | 23.5   | [63]      |
| Caspian Sea, Russia (Asia)      | 1.9    | 0.5    | 200.0  | 32.0   | 3.8    | 14.0   | 8.3    | 17.1   | 0.1    | 4.2    | [64]      |
The correlation between metals in surface sediments is usually related to the discharge of contaminants and their effect on the partitioning of metals in aquatic systems, which may be influenced by differences in the physical, chemical, and biological processes [59,60].

CF in the intertidal zone was very high for Cd and Pb in all localities except El Marageen, and the surf zone showed the same trend. In addition, the CF for Cd and Pb was very high at North Amer El Bahry and July Water Floud. The measured concentrations for some heavy metals in the present study are mainly concerned with the common constituents of oil production activities [54,61,62]. Produced water discharge from oil treatment units and offshore oil wells could be potential sources of metal pollution in the study area. El-Sikaily et al. [63] and Masoud et al. [47] reported that the sediment of the Egyptian Red Sea coast is highly enriched with Cd and Pb, which indicated that Al, Mn, Fe, Cr, Co, Ni, Cu, and Zn were unpolluted across the intertidal and surf zones areas (I_{geo} < 0); however, some localities’ I_{geo} ranged from unpolluted to moderately polluted and from moderately polluted to strongly polluted (July Water Floud, Ras Shokeir, and North Amer El Bahry). Moreover, the I_{geo} index revealed that Cd and Pb were strongly to extremely polluted, except for at Ras Shokeir, which was an unpolluted to moderately polluted area. Relatively higher I_{geo} values for heavy metals in sediment revealed that they originate from an anthropogenic source, especially industrial emissions, such as petroleum activities [6,64]. Accordingly, lower I_{geo} values for metals in the studied sediments may represent natural sources. The contamination is stationed around the produced water discharge pipes and near the petroleum production activities. The data obtained from the present study and the investigation with various categories, sizes, and ecological indices (i.e., contamination factors, enrichment factors, the geoaccumulation index, and the pollution load index), in addition to mineralogy and field observations, revealed that the concentration of heavy metals in the studied area mainly depends on the local prevailing condition in addition to the diagenetic and authigenic resources.

Beyond assessing metal concentrations, evaluating the ecological danger of metals is needed to comprehend possible harmful effects. Heavy metal contamination is a source of concern in the environment, since the metals behave similarly to persistent harmful chemicals. The presence of heavy metals in sediments, which exceeds a permissible amount, will rapidly degrade the ecosystem balance, and deteriorate it [6,22,65]. Heavy metals can be absorbed directly from seawater or indirectly by food by bivalve animals. Another issue is biomagnification, which occurs when toxins accumulate in a food chain from one organism to the next. As a result, further up the food chain, more metals accumulate. The transfer of high concentrations of heavy metals to the body occurs when humans consume polluted species [66]. The Suez Gulf and the adjacent marine ecosystem are characterized by huge colonies of coral reefs and marine nature reserves; consequently, the presence of heavy metals from anthropogenic sources without an environmental monitoring program will degrade such important resources. All of these impacts directly and indirectly affect tourism activities in the Suez Gulf. Since human activity has the greatest impact on semi-closed aquatic environments, effective management and continuous monitoring to identify potential changes and implement the best management practices are needed in these areas. Therefore, the Suez Gulf needs comprehensive investigation into its environmental status.

5. Conclusions

The pH decreased and S‰ increased from north to south. The estimated pH values decreased from north to south at the surf zone. The same observation for a variation in pH values was made based on the distance from the coastline, whereas this value was lower at 200 m from coastline than at 500 m from the coastline. With regard to salinity, it increased from 42‰ in the north to 43.5‰ in the south. The variation in salinity may be attributed to local climatic changes. The sediments at the intertidal zone are mainly composed of well-to moderately sorted gravelly sand and poorly sorted sediments at the surf zone, which is comprised of quartz, feldspars, aragonite, and calcite. The sorting varied from well- to
moderately sorted sediments at the intertidal zone to poorly sorted sediments at the surf zone. The morphological and sedimentological characteristics of the beach area reflect an accretional area that is divided into two main zones: a high accretion rate with a gentle slope beach face, and a relatively low accretion rate with a relatively steep beach face. The heavy metal concentrations average was in descending order: Al > Fe > Mn > Cr > Pb > Cu > Zn > Ni > Co > Cd. The total concentration of Fe, Co, Ni, Cu, Zn, Cd, and Pb along the intertidal and surf zones was the same as or lower than their concentration in other world areas with petroleum activities, while the concentrations of Al, Mn, and Cr were higher than their concentrations in other localities. The contamination factor (CF) average for Cd and Pb was mainly very high at North Amer El Bahry and July Water Floud. The enrichment factor average (EF) reflected anthropogenic sources at North Amer El Bahry, Baker, July Water Floud, and El Marageen, which showed severe enrichment with Zn, Cd, and Pb. The geoaccumulation index ($I_{geo}$) averages for Al, Mn, Fe, Cr, Co, Ni, Cu, and Zn suggest that they are unpolluted metals due to their natural origin, but shows that Cd and Pb are considered polluted metals due to their anthropogenic origin. The pollution load index (PLI) indicates that North Amer El Bahry and July are polluted areas, in addition to Amer at the surf zone. In comparison, the potential ecology risk index (RI) averages indicate that North Amer El Bahry and July Water Floud are source-point-polluted areas due to their anthropogenic origin, which is mainly related to petroleum activities. Chemical analysis showed that, in general, no trend controls the concentration of the heavy metals. The major factor for the configuration of the heavy metals in the studied area may be due to the diagenetic processes and/or the authigenic action affecting the area. However, some correlative values of the average concentrations of heavy metals due to petroleum activities were equal or low when compared to the different sites of petroleum activities all over the world. The presence of heavy metals from anthropogenic sources without an environmental monitoring program will degrade the marine ecosystem, including coral reefs, marine nature reserves, and other nature resources. Consequently, tourism activities will be affected.

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