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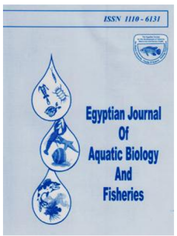

Assessment of Some Heavy Metals and Ecological Risk in Surface Sediments and Water along the El Tur Coast of Suez Gulf, Red Sea, Egypt

Ahmed R. Elgendy, Ahmed R. Hassan, Mohamed A. El-Sawy and Ahmed E. Alprol*
National Institute of Oceanography and Fisheries, NIOF, Cairo, Egypt
*Corresponding Author: ah831992@gmail.com

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ABSTRACT

The monitoring of chemical pollutants of the Red Sea is the initial step to ensure that a healthy marine environment can coexist with necessary human activities. Surface sediments and water samples were collected from El Tur City coast, Gulf of Suez, the Red Sea, Egypt, to determine the extent of heavy metal concentrations, their patterns of distribution, and the ecological concerns connected with the concentrations of heavy metals. Various analysis methodologies assessed the ecological hazards associated with Fe, Zn, Mn, Cu, Cd, Co, Pb, and Ni. For the result of the sediments of El Tur city coast, in the Gulf of Suez, the hydrosoil heavy metal indices were as follows: The order of enrichment factors is: Cd > Co > Pb > Ni > Zn > Mn > Cu. The levels of contamination factors for zinc and copper were low. Furthermore, an average contamination security index of 0.719 was found for all sites, indicating that the majority of the areas under examination were either very clean or very little contaminated. Ecological risk index (ERI) for a single heavy metal pollutant and the potential toxicity response index (RI) for multiple heavy metals in sediments indicate that the Zn, Pb, Cu, Ni, and Cd metals all pose a moderate ecological risk in the El Tur beaches area. At the same time, measurements of water properties revealed depths ranging from 0.9– 10m and temperatures between 18.7–20.7°C. In contrast, the heavy metals were observed for Fe (4.9- 35.1), Mn (0.133– 0.55), Ni (0.37– 1.20), Zn (2.8– 19.55), Cu (0.37– 2.09), Co (0.509–0.64), Pb (0.43– 2.55), and Cd (0.09– 0.3) µg/ l, respectively.

INTRODUCTION

The Red Sea is unique among basins and occupies an excellent position due to its relative isolation from the open oceans and geographical location **(Halim, 1984)**. The richness and splendor of the Red Sea's natural surroundings are among the main draws for tourists across the country and the world **(Initiative, 1995)**. Furthermore, the Red Sea is essential to the world since it links Africa and Asia and allows for extensive marine travel between six nations. The Red Sea has an average width of 280km and a total length of 1930km **(Fahmy, 2010)**. In recent decades, anthropogenic and economic development activities have directly impacted the beaches on the Egyptian side of the Red Sea. Some of these activities include ports for fishing, vacation destinations, urbanization, marine trade, restricted freshwater, phosphate industrial operations, and sewage supply **(El Nemr *et al.*, 2016)**. Red Sea water's dynamics and geographic location determine its hydro-physical and chemical characteristics. It is worth noting that, the Red Sea does not receive significant nutrients from river runoff.

Egypt's massive industrial and commercial growth in recent decades has negatively impacted its Red Sea coast beaches. This group includes ports for tourism and fishing, urban growth, maritime trade, freshwater resources in short supply, the phosphate industry, and wastewater treatment plants. The Sinai Peninsula and ElTur City, east and south, respectively, have hardly noticed any impact from the Suez Gulf oil fields' annual production of more than 250 million barrels of oil. Like the shoreline of the Red Sea, the waters of the Aqaba Gulf are renowned for being excellent diving locations. This region is teeming with aquatic life, especially coral reefs. The Suez Gulf is a well-liked port of call and a significant source of pollution due to its closeness to the Suez Canal, a vital route for international trade **(Elgendy *et al*., 2018)**.

Coastal sediment is a significant sink for heavy metals in the marine environment since it is essential to transferring, complexing, and depositing elements. Furthermore, heavy metals in the ocean are believed to be transported and sourced indirectly from coastal sediments **(Gopal *et al*., 2021)**. Significant health concerns are posed by both anthropogenic and natural sources of heavy metals in the aquatic environment **(El–Moselhy *et al*., 2017)**. Both organic and inorganic pollution are rising faster due to urbanization and development **(Heneash *et al*., 2022)**. Since seawater has specific chemical and physical characteristics, sediments in marine habitats can be both a source and a sink for metals **(Praveena *et al*., 2007)**. Wind or water can deposit heavy metals in coastal sediments. This variation may cause a change in the distribution of dangerous heavy metals between the dissolved and particulate phases **(Alprol *et al*., 2021)**.

This study aimed to monitor the distribution of eight heavy metals (Fe, Mn, Ni, Zn, Pb, Co, Cd, and Cu) in surface water and sediments that were collected from 19 sites along the El Tur coast of Egypt, located on the western side of the Suez Gulf. The objective was to assess the ecological risks associated with these metals, considering that the large volumes of polluted waste that build up in these areas are primarily the result of the activities of tourists, fishermen, water desalination plants, and other enterprises. The surface layer was chosen for this investigation since benthic animals are exposed to it as a metal resource. A multi-index risk assessment of heavy metals and mathematical formulas are required to accurately assess the pollution situation on El Tur, on the Suez Gulf coast.

MATERIALS AND METHODS

1. Preparation and sampling of sediment and water

El Tur, located on Egypt's Suez Gulf coast, was chosen as a representative example. Nineteen surface sea silt samples were collected in March 2020 at depths varying from 0.9 to 10 meters. Surface sediments are the top 10cm of sediment in a sampler. Sediment samples were frozen and sent in polyethylene plastic bags to the laboratory. Before being analyzed, the samples were kept at 4°C. The sediment samples were dried at room temperature until their weights stabilized. While silt and clay were subjected to a pipette method analysis for grain size, sand was sieved dry. The standard procedures outlined in **IAEA (2004)** were followed when collecting the samples. The locations and coordinates of the sampling sites are shown in Fig. (1).

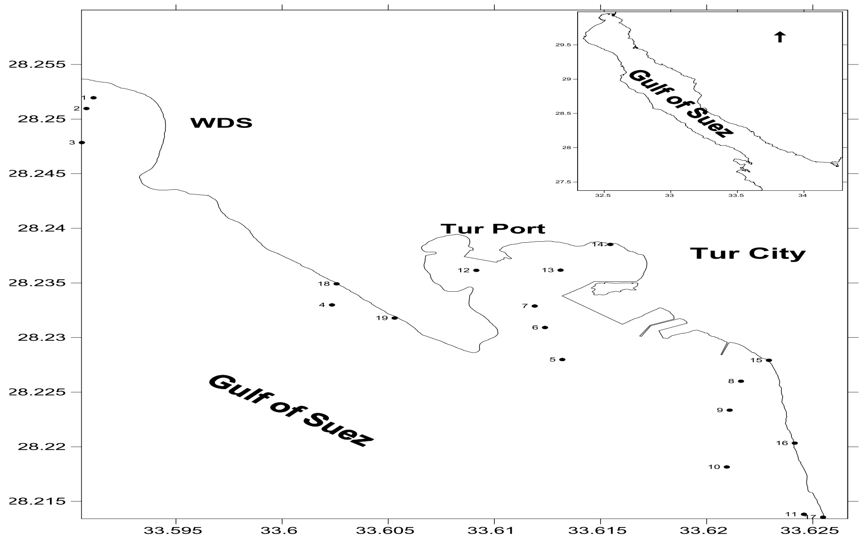

Fig. 1. Map of sampling location of the El Tur of Suez Gulf in the Red Sea

2. Characteristics of surface coastal sediments

2.1. Sediment granulometry

Grain-size distribution was assessed using the dry sieving technique on air-dried sediment samples. Every sample weighed 100g and was sieved using a Ro-Tap shaking machine for 20 meters using a range of mesh sizes (0, 1, 2, 3, and 4). Using the pipetting method, mud (64m) sections of > 5% were removed from silt and clay fractions, following the method outlined by **Ingram (1971)**. Several textural measures, such as mean size (Mz), kurtosis (KG), skewness (SkI), and sorting (I), were calculated using cumulative curve data, following the method of **Folk and Ward (1957)**.

2.2. Geochemical analyses

2.2.1. Estimation of heavy metals in sediments

The sample was dried in an oven at 70°C, put through a 0.75-millimeter plastic sieve, and then broken down for two hours in a 3 : 2 : 1 mix of nitric acid (HNO_3), perchloric acid ($HClO_4$) and hydrochloric acid (HF), according to the method implemented by **Oregon and Aston (1984)**. In this experiment, seven metals (Cu, Pb, Cd, Ni, Zn, Fe, and Co) were measured using an atomic absorption spectrophotometer (ASS) A Anaylist 100. The data were presented as a µg/ g ratio.

2.2.2. Calcium carbonate

To determine the calcium carbonate content, we employed the method implemented by **Jackson (1962)**. Initially, 5g of air-dried soil was transferred to a tall 150-ml beaker. For soils containing more than 30% calcium carbonate, 2.5g of soil was taken, and 100ml of HCl was added using a pipette. The mixture was covered with a clock glass and vigorously stirred for one hour. After settling, 20mL of the mixed liquid was transferred into a small conical flask with phenolphthalein solution as a marker and titrated with 1 N NaOH. A blank titration was performed to account for titratable acidity in the HCl.

2.2.3. Total irganic carbon (TOC)

Piper's method was used to determine organic carbon **(Piper, 1947)**. The total organic carbon (TOC) was calculated using the method published by **Walkley and Black (1934)**, as follows:

$$\text{TOC (\%)} = \text{Organic carbon (g)/ Weight (g)}$$

2.2.4. Grain size analysis and total carbonates

The method proposed by **Folk (1980)** was used to determine the grain size analysis. Total carbonates were calculated by using the formula proposed by **Molnia (1974)**. The following equation is used to calculate total organic matter:

2.2.5. Porosity (Soil pore-space)

The total pore space (cm^3) in sediment is approximately proportional to the water weight (g). Water is supposed to occupy all pore spaces in the soil during saturation. Thus, the principle of determining pore spaces is based on measuring volume in dry conditions. Pore space volume is given as a percentage of the original volume of the soil sample. The soil porosity of the obtained samples was assessed following the method proposed by **Piper (1947)**.

2.3. Ecological risk assessment methods (Pollution assessment)

2.3.1. Geoaccumulation index (Igeo)

The index of geo-accumulation (Igeo) was employed to determine and describe metal contamination in sediments by comparing present concentrations to pre-industrial levels., following the method of **Chakravarty and Patgiri (2009)**, as follows:

$$Igeo = \text{Log2}\,\frac{\text{Cn}}{1.5\text{Bn}}$$

Where, Cn is the observed concentration of heavy metals in sediments; Bn is the geochemical background value of element n in average shale, and 1.5 is the background matrix correction owing to terrigenous effects.

According to **Buccolieri *et al.* (2006)**, there are seven distinct ranges for the geo-accumulation index (Igeo) and they are shown in Table (1).

Table 1. Müller's classification for the geo-accumulation index, I_{geo}

I_{geo} value	**Class**	**Sediment quality**
≤ 0	0	Unpolluted
0-1	1	Unpolluted to moderately polluted
1-2	2	Moderately polluted
2-3	3	Moderately to strongly polluted
3-4	4	Strongly polluted
4-5	5	Strongly to extremely polluted
>5	6	Extremely polluted

2.3.2. Index of pollution load (PLI)

The PLI was employed to estimate how much of a certain environmental factor is in the area, following the method proposed by **Tomlinson *et al.* (1980)**. The PLI for a single location can be calculated by taking the square root of the product of all the contamination factors (CFs) for that location (n), as follows:

$$PLI= (CF1*CF2*CF3\ldots\ldots\ldots CF_n)^{1/n}$$

Where, n is the number of metals (seven in this case) and CF is the contamination factor.

A PLI of zero indicates pristine conditions, whereas a value of one indicates only background amounts of contaminants and values greater than one indicate progressive degradation of the site. When the PLI is greater than 1, pollution is present, while lower values indicate an absence of pollution, as outlined by **Seshan *et al.* (2010)**.

2.3.3. Factor of contamination (CF)

The degree of contamination was quantified using the contamination factor (CF), which indicates the correlation between the concentration of a specific metal and its corresponding background value. This factor was calculated using the following equation: CF = concentration of metals in sample /content in a natural reference or background value

2.3.4. C metal / C background contamination factor (CF)

The base concentrations supplied by **Turekian and Wedepohl (1961)** were used as the basis for the background value, which is derived from element abundances in sedimentary strata. Some common terms for describing the level of contamination include (CF < 1 (low contamination factor); 1 ≤ CF < 3 (moderate contamination factors); 3 ≤ CF < 6 (considerable contamination factors) and CF ≥ 6 (very high contamination factor).

2.3.5. Sediment enrichment factor (SEF)

The SEF formula was used to determine the health status of the sediment, as well as the degree of pollution it contains, following the formula proposed by **Huang and Lin (2003)**, as follows:

$$\mathbf{K_{SEF}} = \frac{\left(\frac{ES}{Als}\right)-\left(\frac{Ea}{Ala}\right)}{\left(\frac{Ea}{Ala}\right)}$$

Where, K_{SEF} is the enrichment factor for heavy metals in sediments. Es and Ea stand for the heavy metal content of examined and unpolluted sediments, respectively. Als and Ala stand for the concentrations of Al in contaminated and uncontaminated sediments, respectively. It was decided to utilize Al as the reference element due to its inertness during the migration. The sediments are highly contaminated with heavy metals if their enrichment factor is large.

2.4. Potential ecological risk index (PERI)

The potential ecological risk index method (PERI) was employed to assess the harm caused by heavy metals in sediments, following the method of **Harikumar and Nasir (2010)**. The procedure, as described by ***Huang et al*. (2004)**, involves the use of the pollution index to assess heavy metal pollution in sediments. C_f^i reflects single heavy metal pollution in sediments, and the formula for single heavy metal pollution index is:

$$\text{Pollution index } C_f^i = \frac{C^i surface}{C^i refrance}$$

Where, C_f^i is the pollution coefficient for a specific heavy metal, which can indicate the pollution character of the researched location but cannot show environmental consequences and hazards.

The formula of E_f^i f for the single heavy metal pollution is deduced as follows:

$$E_f^i = C_f^i \times T_f^i$$

Where, T_f^i is the toxicity response coefficient of a single heavy metal.

The formula exposes the dangers of heavy metals to humans and aquatic ecosystems, as well as the level of heavy metal toxicity and ecological sensitivity to heavy metal contamination. T_f^i stated values for Cd= 30, Cu= Pb= Ni= 5, and Zn= 1, as outlined by **Guo *et al.* (2010)**.

The index of potential toxicity was used to assess the response for several heavy metals in sediments (RI). The RI response index formula for several heavy metals is shown below:

$$RI = \sum E_f^i$$

The grading standards of potential ecological risk of heavy metals are displayed in Table (2).

Table 2. Relationship among RI, E_f^i and pollution levels

Scope of potential ecological	**Ecological risk level**	**Scope of potential**	**General level of potential**
Risk index (E_f^i)	Single-factor pollution	Toxicity index (RI)	Ecological risk
<40	Low	RI<150	Low grade
$40 \leq E_f^i < 80$	Moderate	150≤RI<300	Moderate
$80 \leq E_f^i < 160$	Higher	600≤RI	Severe serious
$160 \leq E_f^i < 320$	High		
$320 \leq E_f^i$	Serious		

2.5. Determination of physicochemical parameters and heavy metals in water

The standards outlined by **APHA (2005)** were used to analyze the physicochemical properties of the water samples gathered in order to estimate numerous factors, such as the water temperature, which was measured using a mercury thermometer. pH was measured with a USA-made model, 59003-20, of pH meter. Additionally, the modified Winkler method was used to determine the levels of dissolved oxygen (DO).

2.6. Determination of the heavy metals in water

For the filtration of the water samples 0.45m membrane filters were used. Ammonium pyrrolidine di-thiocarbamate (APDC) - methyl isobutyl ketone (MIBK) extraction was employed on separate samples of filtrate water to concentrate them, following the guidelines of **APHA (2005)**. Metal concentrations of Fe, Zn, Mn, Cu, Cd, Co, Pb, and Ni were measured using atomic absorption spectrometer.

3. Statistical analysis

The correlation coefficient matrix (r) was generated in SPSS (Version 20) to analyze the various connections between heavy metals in sediment of the investigated area. As expected from a linear relationship, a Pearson's correlation coefficient matrix was calculated for the items.

RESULTS AND DISCUSSION

1. Sediment characteristics

Table (3) displays the sediment parameters, such as water content (WC), carbonate, total organic carbon, total organic matter, sand, silt, mud, and sorting values.

1.1 Grain size analysis

A detailed description of grain size analyses, including mean grain size (Mz), sorting (I), sand, mud, skewness (SK), and kurtosis (KG), are shown in Table (3). All sediment samples collected from El-Tur Coast of the Suez Gulf were made of sand. The predominance of fine particles has been linked to the terrigenous sediments that dominate the Suez Gulf **(Draz *et al.*, 2009)**. The majority of the sites are poorly sorted, with the sorting ranging from reasonably well to poorly. Throughout the whole research region, the percentage of sand varies from 29.2 to 99.70%. The highest percentage of mud (clay) is found at station El Tur 6 (50%).

1.2. Calcium carbonates and total organic matter

The $CaCO_3$ content ranges from 22.78% in El Tur 2 to 96.12% in El Tur 2, with a mean of 55.36% (Fig. 2). An increase in terrestrial carbonate-rich shell pieces is correlated with a larger proportion **(El nemer *et al.*, 2016)**. The distribution of carbonate is influenced by the motion and flow of shells across the bottom. Moreover, chemical and biological carbonate precipitation may happen in shallow, highly salinized, and warm waters **(de Mora *et al.*, 2004)**. Total organic matter ranged from 22.78 to 96.12, with an average of 55.36mg/ g (site 2) (Fig. 2). The fish farms and desalination plant were found to have the highest quantities of organic carbon, probably due to sewage outflows in the area.

1.3. Heavy metals in the sediment samples

Figs. (3, 4) compare the heavy metal concentrations in El Tur hydrosoil samples from various locales.

The most prevalent heavy metal, iron (Fe), was present in significant concentrations in the El Tur sediments of the Suez Gulf; average 8052.05µg/ g and ranged from 258.5 (site 4) to 22840 (site 12). These values are significantly higher than the recommended safe upper limit of 15µg/ g that is recommended by the **WHO (2004)**. The observed variation in iron content throughout the study region could be explained by the mineral composition of sediments **(Coulibaly *et al.*, 2006)**. The highest concentrations at these locations (site 15) are beyond the **EPA (2002)** limit value of 25µg/ g, but below the **EU (2002)** limit of 140µg/ g. Oral toxicity of zinc compounds in humans is rather low, even though zinc is one of the most common dangerous heavy metals **(Helstead, 1974)**. The reported Zn value for these sites is under the proposed **EU (2002**) limit of 300µg/ g and less than the projected limit of 123µg/ g set by the **EPA (2002)**.

Discharging industrial waste, particularly from creating synthetic fibers and electroplating, can cause increased quantities of zinc in aquatic habitats. Zinc-containing commercial products, home waste, and industrial effluents are the main sources of zinc concentrations in the environment, such as soil, water, and air **(Garcia & Millan, 1998)**.

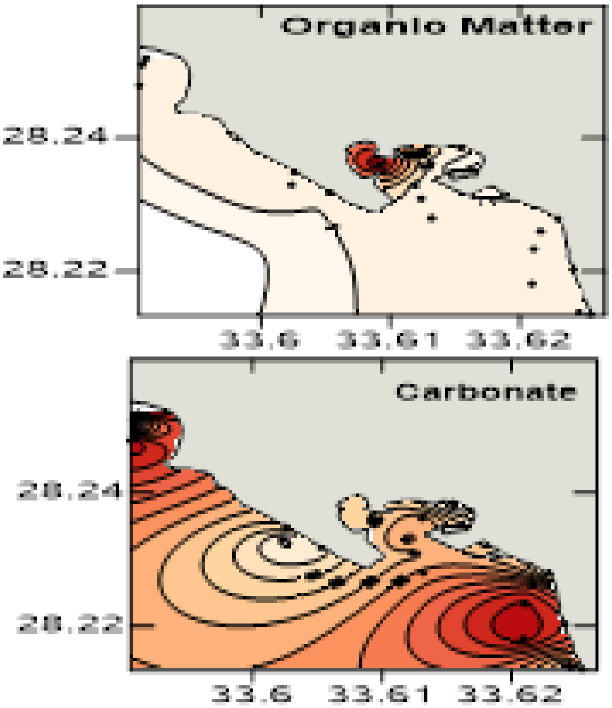

Fig. 2. Distribuion of calcium carbonates and total organic matter concentrations in sediments along the El Tur coast, the Red Sea, Egypt

A "black registered element," cadmium is highly harmful to both humans and aquatic life. Cadmium levels in El Tur silt from the Suez Gulf are averaged at 14.58µg/ g. The results data ranged from 9.88 to 20.16µg/ g. The petroleum and phosphate industries have the greatest levels of lead. At these areas, the maximum permitted Cd levels exceeded the limit set by the **EU (2002)** at 3µg/ g and the **EPA (2002)** at 6µg/ g. **Allaway (1968)** stated that the maximum amount of cadmium that is permitted in uncontaminated soils is 0.7mg/ l. Since it is more easily consumed, cadmium in high amounts in sediment is particularly hazardous. The amounts of cobalt in the beach sediments of El Tur likewise varied greatly, averaging 44.94µg/ g and ranging from 25.99 at site 2 to 68.35µg/ g at site 7. Lead metal concentrations in the coastal sediment of El Tur varied equally, with a mean value of 14.58µg/ g. They ranged from 9.882 (site 2) to 20.16µg/ g (site 9). The mean Mn concentration in the coastal sediments of El Tur was 294.88 µg/g, with values ranging from 64.90 (site 4) to 561.80µg/ g (site 7). In decreasing order of abundance, the heavy metals identified in this study are Mn, Ni, Zn, Pb, Co, Cd, and Cu, with Fe bring the most prevalent when compared to others. Fe, Mn, Ni, Zn, Pb, Co, Cd, and Cu have average values of 8052.05, 294.8, 90.37, 78.02, 72.81, 44.94, 14.58, and 12.35µg/ g. A study carried out in cooperation with **El nemer *et al.* (2016)** found that the average concentrations of Ni, Cu, Zn, Pb, and Cd in El Tur in the Suez Gulf are greater presently than they were in 2012. According to **Elmoselhy and Hamed (2000)**, there are higher than predicted concentrations of Ni, Co, Fe, Mn, Pb, Zn, and Cd in the Suez Gulf. The amount and kind of input water, along with other factors including soil structure and features, often influence the dispersion of heavy metals is in these areas.

Table 3. Characteristics of surface coastal sediments along the El Tur coast, Red Sea, Egypt

Station ID	**T.O. M%**	**Ca CO_3 %**	**Mean grain size (Mz)**	**Sorting (δI)**	**Skewness (SK)**	**Kurtosis (KG)**	**Gravel**	**Sand**	**Mud**
1	0.94	96.12	Fine sand	Moderately well sorted	Symmetrical	Leptokurtic	0.00%	99.70%	0.30%
2	1.03	22.78	Fine sand	Moderately well sorted	Coarse skewed	Platykurtic	0.00%	99.60%	0.40%
3	1.23	84.99	Fine sand	Moderately well sorted	Symmetrical	Leptokurtic	0.00%	99.20%	0.80%
4	5.09	28.97	Coarse sand	Poorly sorted	Symmetrical	Mesokurtic	0.00%	99.70%	0.30%
5	3.40	56.68	Very fine sand	Poorly sorted	Very coarse skewed	Leptokurtic	0.00%	52.60%	47.40%
6	3.39	48.57	Very fine sand	Poorly sorted	Very coarse skewed	Leptokurtic	0.00%	50.00%	50.00%
7	3.26	56.21	Fine Sand	Poorly sorted	Very coarse skewed	Platykurtic	0.00%	64.10%	35.90%
8	2.77	71.31	Medium sand	Poorly sorted	Fine skewed	Very platykurtic	0.00%	97.60%	2.40%
9	2.87	80.98	Coarse sand	Moderately sorted	Coarse skewed	Very platykurtic	0.00%	99.60%	0.40%
10	3.19	83.59	Coarse sand	Poorly sorted	Coarse skewed	Mesokurtic	0.00%	99.70%	0.30%
11	3.68	41.40	Fine sand	Poorly sorted	Symmetrical	Platykurtic	0.00%	94.80%	5.20%
12	35.05	43.20	Very coarse silt	Poorly sorted	Very coarse skewed	Very leptokurtic	0.00%	29.20%	70.80%
13	2.45	54.37	Fine sand	Poorly sorted	Very coarse skewed	Platykurtic	0.00%	74.30%	25.70%
14	2.05	23.16	Very fine sand	Poorly sorted	Very coarse skewed	Very leptokurtic	0.00%	97.80%	2.20%
15	3.03	38.03	Fine sand	Poorly sorted	Very coarse	Very	0.00%	96.20%	3.80%

					skewed	leptokurtic			
16	3.05	74.81	Medium sand	Poorly sorted	Symmetrical	Mesokurtic	0.00%	92.10%	7.90%
17	3.26	70.22	Fine sand	Poorly sorted	Very coarse skewed	Platykurtic	0.00%	94.00%	6.00%
18	2.10	44.24	Fine sand	Poorly sorted	Very coarse skewed	Very platykurtic	0.00%	93.40%	6.60%
19	1.37	32.28	Fine sand	Poorly sorted	Very coarse skewed	Leptokurtic	0.00%	96.80%	3.20%

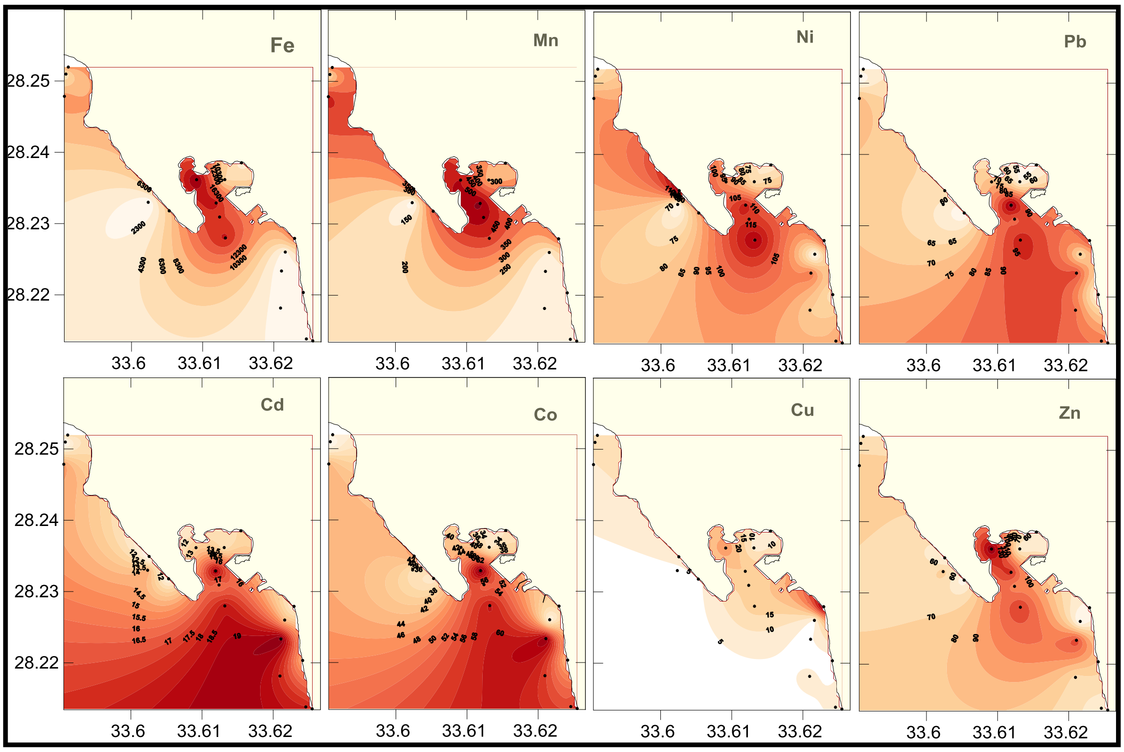

Fig. 3. Distribution of the heavy metals in sediment at the El Tur of the Red Sea coast

1.4. Geo-accumulation index (Igeo)

All of the metals under investigation have geo-accumulation index average values that fall between 0 and 1. This eliminates the chance of pollution in the area under investigation. Table (4) presents the results of Igeo. The lack of Ni, Cu, and Zn in the negative results suggests that the sampling sites are not contaminated with these elements, according to the categorization of **Muller (1969)**. The Pb and Co Igeo values ranged from clean to mildly polluted, according to the geo-accumulation index. In contrast, the Cd ions were highly contaminated.

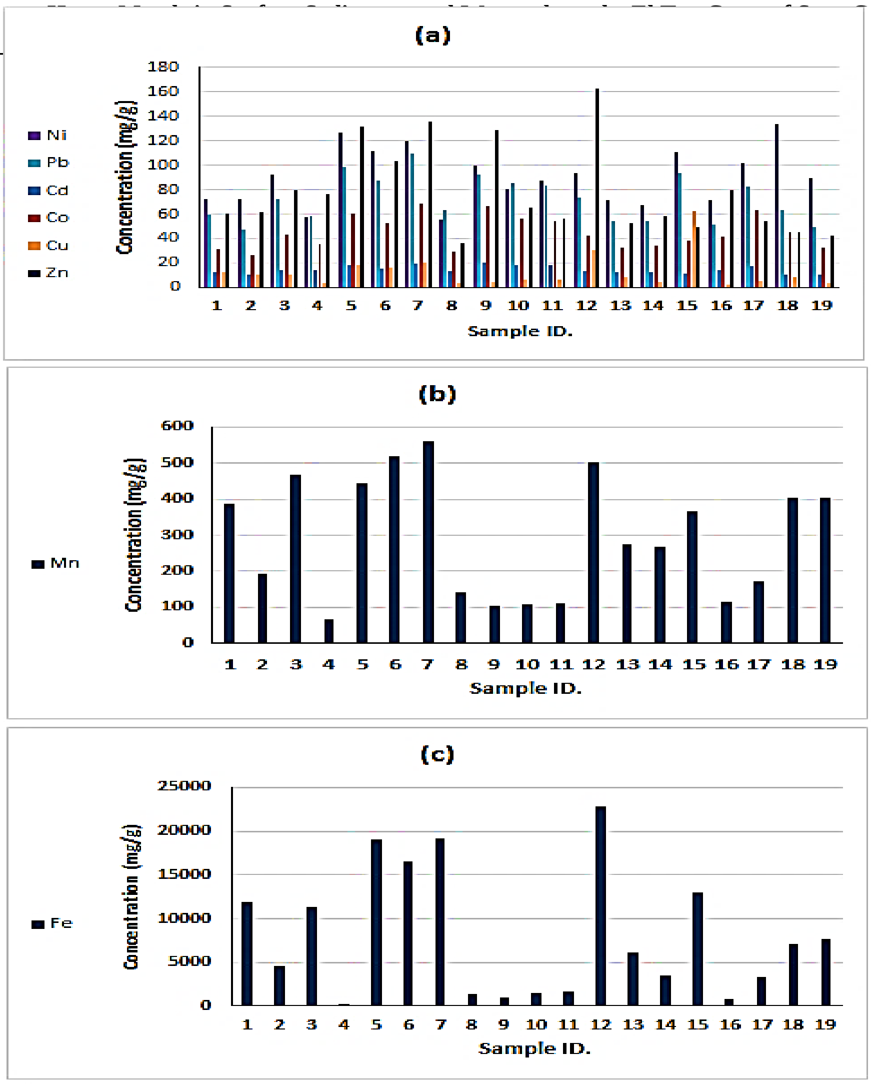

Fig. 4. The concentrations levels of heavy metals in the sediment of El Tur of the Red sea coast considering: **a.** Ni, Zn, Pb, Co, Cd, and Cu, **b.** Mn, and **c.** Fe

Table 4. Geo-accumulation index (Igeo) and pollution load index (PLI) of heavy metals in surface sediments

Station	Ni	Pb	Cd	Co	Cu	Zn	PLI
1	-0.48	1.00	4.81	0.13	-2.49	-1.23	1.83
2	-0.49	0.66	4.46	-0.13	-2.73	-1.22	1.60
3	-0.15	1.28	5.03	0.59	-2.77	-0.84	2.16
4	-0.83	0.97	5.00	0.31	-4.44	-0.90	1.52
5	0.31	1.72	5.36	1.09	-1.91	-0.11	3.16
6	0.13	1.55	5.14	0.87	-2.05	-0.46	2.73
7	0.23	1.88	5.44	1.26	-1.74	-0.07	3.36
8	-0.87	1.08	4.94	0.05	-4.21	-1.96	1.34
9	-0.03	1.63	5.49	1.23	-3.86	-0.14	2.47
10	-0.35	1.52	5.31	0.99	-3.39	-1.11	2.12
11	-0.21	1.48	5.32	0.94	-3.53	-1.35	2.04
12	-0.12	1.29	4.87	0.57	-1.17	0.20	2.88
13	-0.51	0.85	4.74	0.20	-3.02	-1.43	1.65
14	-0.60	0.85	4.82	0.26	-3.97	-1.27	1.51

15	0.12	1.64	4.64	0.42	-0.10	-1.52	2.73
16	-0.52	0.78	4.98	0.54	-4.78	-0.85	1.53
17	0.00	1.46	5.30	1.15	-3.79	-1.38	2.06
18	0.39	1.09	4.50	0.67	-3.04	-1.66	1.88
19	-0.19	0.73	4.57	0.18	-4.27	-1.76	1.38

1.5. Contamination factor (CF)

The background value obtained from element abundances in sedimentary strata is based on the base concentrations published by **Turekian and Wedepohl (1961)**. In this study, describing the contamination factor involves using words, such as low, moderate, high, and extremely high contamination factors. Copper and zinc have relatively low contamination factors. Both nickel and cobalt showed a moderate level of contamination. While, lead and cadmium CF values above 3 indicate a high contamination factor, as displayed in Table (5).

Table 5. Contamination factor (CF) of heavy metals in the surface sediments

Station	Ni	Pb	Cd	Co	Cu	Zn
1	1.07	2.99	41.93	1.64	0.27	0.64
2	1.07	2.38	32.94	1.37	0.23	0.65
3	1.36	3.64	49.03	2.26	0.22	0.84
4	0.85	2.94	48.07	1.86	0.07	0.80
5	1.86	4.94	61.47	3.19	0.40	1.39
6	1.65	4.39	52.83	2.75	0.36	1.09
7	1.76	5.51	64.93	3.60	0.45	1.43
8	0.82	3.17	46.00	1.55	0.08	0.38
9	1.47	4.64	67.20	3.53	0.10	1.36
10	1.18	4.30	59.63	2.98	0.14	0.69
11	1.29	4.17	60.10	2.87	0.13	0.59
12	1.38	3.66	44.00	2.22	0.67	1.72
13	1.05	2.71	40.17	1.73	0.18	0.55
14	0.99	2.70	42.30	1.80	0.10	0.62
15	1.63	4.66	37.47	2.01	1.40	0.52
16	1.05	2.58	47.20	2.18	0.05	0.83
17	1.50	4.13	59.00	3.33	0.11	0.58
18	1.97	3.19	33.90	2.39	0.18	0.48
19	1.31	2.49	35.53	1.70	0.08	0.44

2. Potential ecological risk index

2.1. Sediment enrichment factor (EF) of heavy metals in El Tur sediments

Zn enrichment in the El Tur sediments was moderate, with enrichment factors ranging from 0.02 to 45.55. Significant enrichment was seen for Mn (0.91– 10.43) and Cu (0.15– 3.93) over a broad range of EF values. The enrichment factor (EF) values for Pb, Co, and Cd were found to be between 0.84 and 45.32 (moderate enrichment), 1.08 and 79.60 (also moderate enrichment), 1.45 to 140.02 (low enrichment), and 0.82 to 58.20 (moderate enrichment), respectively. As EF values increase, the percentage of the enrichment factor that may be attributed to human activity also increases. The El Tur deposits' heavy metal content is arranged according to the enrichment factor sequence: Cd, Co, Pb, Ni, Zn, Mn, and Cu. Therefore, copper makes up the smallest quantity, while cadmium predominates over other metals.

The majority of the sediment samples in the study area have Eif and RI values more than 201, indicating the potential toxicity response index for multiple heavy metals in sediments and the ecological risk index for a single heavy metal pollution (Table 6). This indicates that, while the remainder of the metals at El Tur's beaches poses a minimal risk, Zn, Pb, Cu, Ni, and Cd at station no. 9 pose an extremely high ecological risk.

Table 6. Ecological risk index (ERI) for several heavy metals in El Tur sediments

Station	**ERI**					**RI**
	Ni	**Pb**	**Cd**	**Cu**	**Zn**	
1	5.36	14.96	1258.00	1.33	0.64	1280.30
2	5.34	11.89	988.20	1.13	0.65	1007.20
3	6.78	18.19	1471.00	1.10	0.84	1497.91
4	4.23	14.70	1442.00	0.35	0.80	1462.08
5	9.31	24.70	1844.00	2.00	1.39	1881.39
6	8.24	21.95	1585.00	1.81	1.09	1618.09
7	8.79	27.53	1948.00	2.24	1.43	1987.98
8	4.09	15.85	1380.00	0.40	0.38	1400.73
9	7.35	23.20	2016.00	0.52	1.36	2048.42
10	5.89	21.48	1789.00	0.72	0.69	1817.78
11	6.47	20.85	1803.00	0.65	0.59	1831.56
12	6.91	18.29	1320.00	3.34	1.72	1350.26
13	5.25	13.56	1205.00	0.92	0.55	1225.29
14	4.95	13.51	1269.00	0.48	0.62	1288.55
15	8.15	23.30	1124.00	6.99	0.52	1162.96
16	5.24	12.92	1416.00	0.27	0.83	1435.27
17	7.50	20.65	1770.00	0.54	0.58	1799.26
18	9.83	15.94	1017.00	0.91	0.48	1044.16
19	6.57	12.44	1066.00	0.39	0.44	1085.85

2.2. Index of contamination security (CSI)

The CSI results showed that the majority of the sites studied were uncontaminated to low in severity (CSI 0.5; 0.5 > CSI 1, respectively), with an average for all sites (0.719), as exhibited in Table (7).

Table 7. Index of contamination security in El Tur sediments

Station	Ni	Pb	Cd	Cu	Zn	Average
1	0.804	0.180	1.740	0.013	0.017	0.551
2	0.800	0.140	1.294	0.011	0.017	0.452
3	1.160	0.223	2.119	0.011	0.023	0.707
4	0.563	0.176	2.066	0.003	0.022	0.566
5	1.945	0.317	2.843	0.020	0.041	1.033
6	1.589	0.277	2.333	0.018	0.031	0.849
7	1.768	0.360	3.059	0.023	0.042	1.050
8	0.536	0.192	1.954	0.004	0.010	0.539
9	1.321	0.295	3.203	0.005	0.040	0.973
10	0.930	0.270	2.732	0.007	0.018	0.791
11	1.079	0.261	2.760	0.006	0.015	0.824
12	1.197	0.225	1.848	0.034	0.053	0.671
13	0.779	0.161	1.649	0.009	0.014	0.523
14	0.712	0.161	1.759	0.005	0.016	0.530
15	1.561	0.296	1.514	0.073	0.014	0.692
16	0.778	0.153	2.019	0.003	0.023	0.595
17	1.365	0.258	2.694	0.005	0.015	0.867
18	2.131	0.193	1.340	0.009	0.012	0.737
19	1.105	0.147	1.419	0.004	0.011	0.537
Average	**1.164**	**0.225**	**2.123**	**0.014**	**0.023**	**0.710**

3. Assessment of physical and chemical parameters in water

The results of physical and chemical analyses of water samples taken from different habitats in El Tur in the Suez Gulf (13) are displayed in Table (8). El Tur in the Suez Gulf has an average water depth of 5.73 meters, with a range of 0.9 to 10 meters (site 4). The mean temperature was 19.7°C, with a range of 18.7 to 20.7°C. Water samples had a pH ranging from 8.1 at El Tur 1 to 8.62 close to El Tur 19, with an average of 8.44. Many local activities (i.e., household or anthropogenic activities) may be connected to the high pH value. **WHO (2004)** suggested that the pH value should vary between 6.5 to 8.5. According to the obtained results, dissolved oxygen ranged from 7.3 at El Tur 17 to 12.6mg/ l at El Tur 8, with a mean value of 10.65mg/ l. Based on these findings and the allowed limits (4.0- 5.0mg/ L) are determined according to **Mishra *et al.* (2008)**. The water on the El Tur coast poses little hazard to aquatic life.

4. Heavy metals in water

The results of physical and chemical analyses of water samples taken from different habitats in El Tur in the Suez Gulf (13) are displayed in Table (8). El Tur in the Suez Gulf has an average water depth of 5.73 meters, with a range of 0.9 to 10 meters (site 4). The mean temperature was 19.7°C, with a range of 18.7 to 20.7°C. Water samples had a pH ranging from 8.1 at El Tur 1 to 8.62 close to El Tur 19, with an average of 8.44. Many local activities (i.e., household or anthropogenic activities) may be connected to the high pH value.

The average concentration of manganese (Mn) ranged from 0.133 to 0.55µg/ l. These values are significantly lower than the 50,000µg/ l EU limit set in 2002. Within a range of 0.37- 1.20µg/ l, the average concentration of nickel (Ni) in the water was 0.65µg/ l. The zinc (Zn) concentration range in El Tur shore water is 2.8– 19.55µg/ l, with an average of 8.43µg/ l.

Copper (Cu) concentrations in the El Tur coastal habitat water ranged from 0.37 at the nearby El Tur 19 site to 2.09 at the El Tur 1 site, with an average of 0.749µg/ l. In receiving water bodies, the Egyptian standards for copper and zinc (out of 1000µg/ l) are relatively strict compared to European norms (50µg/ l for copper and 150µg/ l for zinc).

Cobalt (Co) ions were present in the El Tur beach water; the cobalt concentrations ranged from 0.509 to 0.164µg/ l, with a mean value of 0.27µg/ l. These values are below the 5000µg/ l permissible limit that is reported by **EPA (2002**).

Lead (Pb) ion concentrations in the water at El Tur beaches ranged from 0.43 to 2.55µg/ l, with a mean value of 1.06µg/ l. Lead levels in El Tur's water are below the threshold that is indicated by **EPA (2002)**, making it safe to consume. According to **USEPA (1986)**, lead is exceedingly harmful to all known forms of life. Cadmium (Cd) ions have been found to be harmful at concentrations of 0.01mg/ L in drinking or irrigation water **(Goering *et al*., 1994)**. Due to its broad carcinogenic effects on humans, cadmium is considered one of the most dangerous metals. The water along the beaches of El Tur had an average cadmium concentration of 0.155µg/ l, ranging from 0.09 to 0.3µg/ l. The source of the greatest average concentration (0.3µg/ l) at site 1, which was caused by desalination plant effluents, is most likely mineral and soil weathering, residential effluent discharge, and urban storm-water runoff that carries Cd-laden debris. The most frequent routes for metals to enter aquatic environments are through anthropogenic sources or geological matrix erosion.

El Tur supports the following order of elements: Fe > Zn > Pb > Cu > Ni> Mn Co> Cd. While, Zn and Cu are physiologically significant and natural constituents of aquatic ecosystems; they become dangerous only at extremely high amounts (especially lead and cadmium).

5. Statistical analyses

Since the correlation coefficient "r" is a crucial statistical test for assessing the robustness or fragility of the correlations between trace metal concentrations, a Pearson's correlation coefficient matrix was calculated. Table (9) displays the Pearson correlations for the heavy metal concentrations examined in the sediments of El Tur in the Suez Gulf. Mn and Fe have a strong positive association (r = 0.914), as do Ni and Fe (r = 0.589), Ni and Mn (r=0.610), Pb and Fe (r = 0.448) and Ni (0.672), and Cd and Pb (r = 0.760). Co and Ni have a correlation of 0.639, Co and Pb of 0.846, and Co and Cd of 0.880. Zn and Pb (r=0.545), Zn and Cd (r=0.525), and Zn and Co (r=0.541) are all positively correlated with copper and iron. Furthermore, a substantial negative connection showed weak correlations between the elements analyzed, which may demonstrate the presence of many sources for the intake of heavy metals to the El Ture in the Suez Gulf. Total organic matter was also found to have a positive connection with all heavy metals with the exception of cadmium. However, heavy metals and sand % were shown to have a statistically significant negative connection (*P*= 0.05).

Table 8. Average concentration of physical and chemical parameters in water samples collected from El Tur coast

Sample ID	Depth (m)	Temp (°C)	Do (mg/l)	pH	Fe (µg/l)	Mn (µg/l)	Ni (µg/l)	Pb (µg/l)	Cd (µg/l)	Co (µg/l)	Cu (µg/l)	Zn (µg/l)
1	4	20.3	9.8	8.18	20.36	0.305	1.206	2.556	0.3	0.509	2.095	19.55
2	8	19.4	10.7	8.24	11.64	0.348	0.582	0.959	0.155	0.228	0.723	13.29
3	10	19.4	12.2	8.25	15.43	0.456	0.851	1.122	0.177	0.354	0.678	7.189
4	5	19.2	10.6	8.3	11.22	0.219	0.642	1.285	0.128	0.22	0.533	6.901
5	4	19.6	12.6	8.41	8.617	0.278	0.71	1.071	0.184	0.448	0.426	4.633
6	7	19.3	11.8	8.46	16.41	0.235	0.783	1.152	0.155	0.227	0.9	11.45
7	7	18.7	12.3	8.5	14.05	0.199	0.728	0.838	0.098	0.164	0.822	8.081
8	0.9	19.4	10.5	8.6	14.89	0.555	0.444	0.539	0.122	0.245	0.61	5.391
9	Beach	20.7	9.7	8.6	8.509	0.177	0.433	0.435	0.121	0.214	0.411	2.899
10	Beach	19.9	7.3	8.53	10.68	0.271	0.49	0.539	0.121	0.184	0.556	6.535
11	Beach	20	9.9	8.62	35.1	0.367	0.625	1.483	0.163	0.288	0.86	9.494
12	Beach	20.5	10.5	8.62	4.9	0.133	0.375	0.85	0.145	0.18	0.378	5.857

Fig. (5) presents the results of principal component analysis (PCA) performed on the collected data, which revealed that two components accounted for 46.26 percent of the total and had an eigenvalue of 5.55. Sand was negatively loaded on PC1, while all other variables were positively loaded. PC2 was negatively loaded with mud, TOM, Fe, Mn, and Cu and positively loaded with sand $CaCO_3$, Ni, Cd, Co, Pb, and Zn.

Similarity between the mixed stations within a site was exceptionally strong, as determined by cluster analysis (spatial similarity and site grouping) **(El-Feky *et al*., 2018)**. Afterward, we combined the data into a dendrogram, and in Fig. (6) you can detect the similarity coefficients of all the stations under study in the El Tur in the Suez Gulf based on their sediment similarities. Five statistically significant clusters were found to exist, with site 12 being the least representative and site 13 being the most representative. Cluster 1 (C1) was comprised of stations 1, 3, and 5. Stations 5, 7, and 7 made up Cluster 2 (C2), which was located near the port of El Tur and shared characteristics with Site 12. Cluster 3 (C3), meanwhile, corresponded to stations 2, 14, and 17. However, C4 was made up of stations 4, 8, and 10 and they all correspond to site 11. Cluster 5 (C5), on the other hand, is linked to stations 13 and 18, which have similar characteristics; this suggests that the variations across the groups reflect distinct contamination origins.

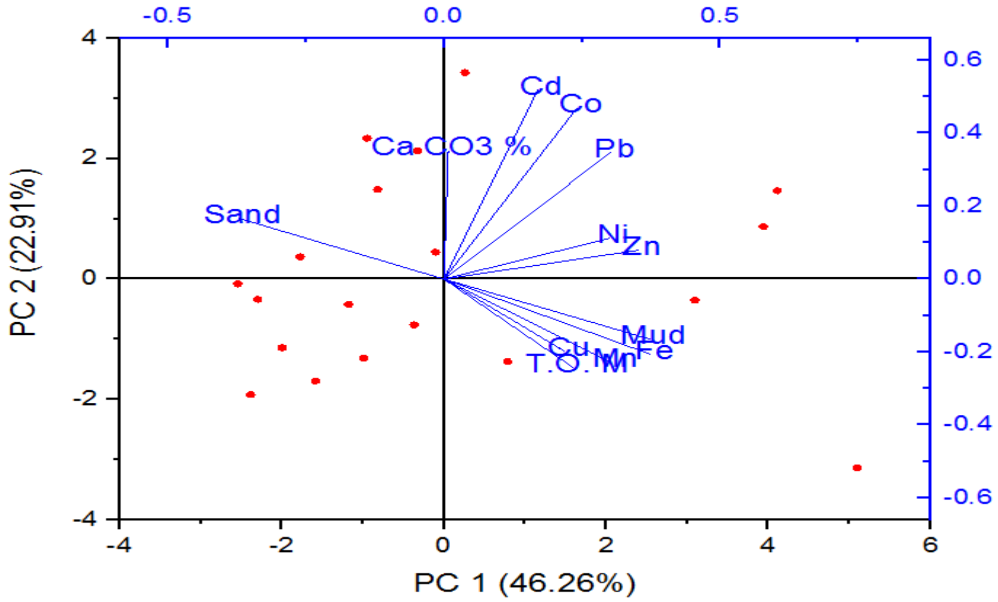

Fig. 5. R-mode PCA ordination diagram of PC1 vs. PC2

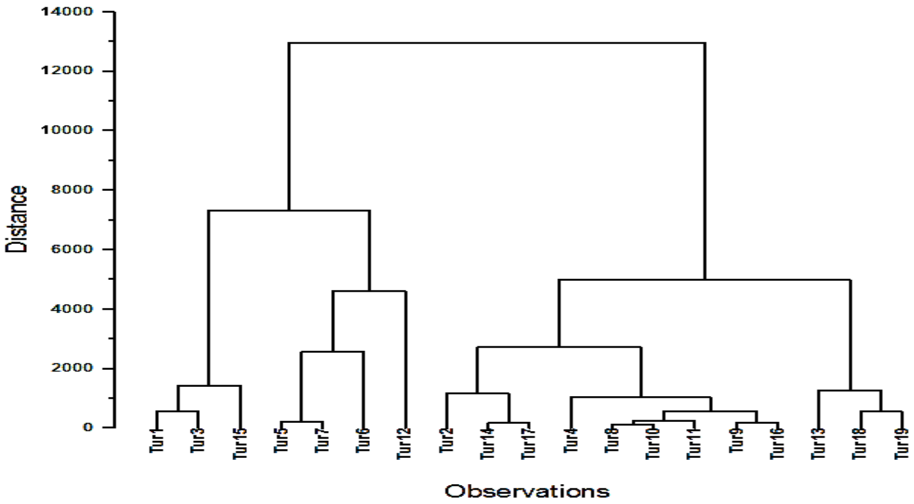

Fig. 6. Dendrogram viewing the relationship amongst sampling locations in El Tur of Suez Gulf

Table 9. Pearson's correlation coefficient for variables

	Sand %	**T.O.M%**	**Ca CO$_3$ %**	**Fe**	**Mn**	**Ni**	**Pb**	**Cd**	**Co**	**Cu**	**Zn**
Sand %	1										
T.O. M%	-.672-**	1									
Ca CO$_3$ %	.143	-.148	1								
Fe	-.802-**	.477*	-.055	1							
Mn	-.627-**	.253	-.070	**.914****	1						
Ni	-.428	.048	-.016	.589**	.610**	1					
Pb	-.373	.067	.244	.448	.295	.672**	1				
Cd	-.185	-.026	.439	.023	-.135	.260	.760**	1			
Co	-.279	.015	.323	.187	.087	.639**	.846**	.880**	1		
Cu	-.337	.307	-.189	.607**	.464*	.420	.441	-.163	.008	1	
Zn	-.742-**	.591**	.099	.628**	.407	.390	.545*	.525*	.541*	.218	**1**

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

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

Very Strong **Strong** **Moderate** **Weak**

CONCLUSION

Pollution has become a severe issue since industry, agriculture, and urban populations have grown. As a result, evaluating water and sediment quality is an important objective. Granulometric research revealed a variety of facies in El Tur coastal sediment, including coarse sand, medium sand, and fine sand. The results revealed that Fe and Mn were the most abundant elements in all samples under study. The enrichment factor (EF) takes the following arrangement: Cd > Co > Pb > Ni > Zn > Mn > Cu. The pollution load index (PLI) gives an indication of pollution in the El Tur of the Suez Gulf. While, the geoaccumulation index (Igeo) showed that El Tur of the Suez Gulf was most polluted with Cd metal. A correlation matrix assessment was carried out to check the significant relationship between heavy metal parameters.

Finally, the findings of this study would be significant and helpful for future research and economic development since they provide current data on contamination levels in the El Tur of the Suez Gulf and the Red Sea marine sediments. Furthermore, the current findings could serve as a solid foundation for developing local standards. To avoid environmental dangers, concentrations along the Red Sea shoreline must be evaluated on a regular basis.

REFERENCES

Ajayan, K. V. and Parameswara Naik, T. (2014). Physico-Chemical Characteristics of a Fresh Water Lake Koppa, Bhadravathi Taluk, Shimoga District, Karnataka, India. Int. Res. J. Environ. Sci., 3 (11): 52-56.

Allaway, W. H. (1968). Agronomic controls over environmental cycling of trace elements. Adv. Agron., 20: 235–274.

Alprol, A.E.; Heneash‹ A.M.M. ; Soliman, A.M.; Ashour, M.; Alsanie,W.F.; Gaber, A. and Mansour‹ A.T. (2021). Assessment of Water Quality‹ Eutrophication, and Zooplankton Community in Lake Burullus, Egypt. Diversity, 13: 268-287 **https//: doi.org/10.3390/d13060268**

Buccolieri, A.; Buccolieri, G. and Cardellicchio, N. (2006). Heavy Metals in Marine Sediments of Taranto Gulf (Ionian Sea, Southern Italy). Mar. Chem., 99, 227–235.

Initiative C. R. (1995). State ofthe reefs: regional and global perspectives. Inter. Coral Reef Initiative, US Department of State, Washington, DC,.

Chakravarty, M. and Patgiri, A. D. (2009). Metal pollution assessment in sediments of the Dikrong River, NE India. J. Hum. Ecol., 27 (1) : 63-67.

Coulibaly, A. S., Anschutz, P., Blanc, G., Malaize, B., Pujol, C., and Fontanier, C. (2006). The effect of paleo-oceanographic changes on the sedimentary recording of hydrothermal activity in the Red Sea during the last 30,000 years. Mar. Geol., 226: 51–64.

Draz, S. E. O.; Youssef, D. H. and El-Said, G. F. (2009). Sedimentological characterisrics and distribution of fluoride in granulometric fractions of subsurface sediments in Suez and Aqaba gulf, Egypt. J. Egypt. Acad. Soc. Environ. Dev. D—Environmental Stud., 10 (1): 73–91.

El-Feky, M. M. M.; Alprol, A. E.; Heneash, A. M. M.; Abo-Taleb, H. A. and Omer, M. Y. (2018) Evaluation of water quality and plankton for mahmoudia canal in Northern west of Egypt. Egypt. J. Aquat. Biol. Fish., 22 (5): 1-24.

El–Moselhy, K. M.; Abdel-Azzem, M.; Amer, A.; Al-Prol, A. E. (2017). Adsorption of Cu (II) and Cd (II) from aqueous solution by using rice husk adsorbent. Phys. Chem. An Indian J., 12 (2): 109-124.

El-Moselhy, K.H.M. and Hamed, M.A. (2000). Pollution by mercury and tin in water and sediments of the Red Sea coasts, Egypt. J. Environ. Sci., 19: 29-41.

El nemer, A.; El-said, G. F.; Khaled, A. and Ragab, S. (2016). Distribution and ecological risk assessment of some heavy metals in coastal surface sediments along the Red Sea , Egypt. Int. J. Sediment Res., 31 (2): 164–172.

EPA. (2002) Environmental Protection Agency. National Recommended Water Quality Criteria, USA, 822-R-02-047.

Fahmy, M. (2010). Water quality in the Red Sea coastal waters (Egypt): Analysis of spatial and temporal variability. Chem. Ecol., 19: 67–77.

Federation, W. E. (2005). Association Standard Methods for the Examination ofWater and Wastewater, 21st ed.; American Public Health Association (APHA): Washington, DC, USA.

Folk, R.L. and Ward, W. C. (1957). Brazos River bar [Texas]; a study in the significance of grain size parameters. J. Sediment. Res., 27: 3–26.

Folk, R. L. (1980). Petrology of sedimentary rocks (p. 182) Austin, Texas: Hemphill Publishing Company.

Garcia, R. and Millan, E. (1998). Assessment of Cd, Pb and Zn contamination in roadside soils and grasses from Gipuzkoa (Spain). Chemosphere, 37: 1615-1625.

Goering, P. L.; Waalkes M. P. and Klaassen, C. D. (1994). Toxicology of metals. In Zinc supplement overdose can have toxic effects. (R. Hess and B. Schmidt, ed.). J. Paediar, Haemetol., 24: 528–584.

Gopal, V.; Krishnamurthy, R.R.; Sreeshma, T.; Chakraborty, P.; Nathan, C.S.; Kalaivanan, R.; Anshu, R. and Magesh, N. S. . J. (2021). Effect of a tropical cyclone on the distribution of heavy metals in the marine sediments off Kameswaram, Southeast coast of India. Mar. Pollut. Bull., 171: 112741.

Guo, W.H.; Liu, X.B.; Liu, Z.G. and Li, G. F. (2010). Pollution and potential ecological risk evaluation of heavy metals in the sediments around Dongjiang Harbor, Tianjin. Procedia Environmental Sciences. International society for environmental information sciences 2010 annual conference, 2: 729–736.

Harikumar, P. S. and Nasir, U. P. (2010). Ecotoxicological impact assessment of heavy metals in core sediments of a tropical estuary. Ecotoxicol. Environ. Saf., 73 :1742–

1747.

Helstead. (1974). Toxicity of Marine Organisms Caused by Pollution, Marine Pollution and Sea Life, Fishing News Books, Ltd. London.

Heneash, A. M.; Alprol, A. E.; El, H. A.; Samiha, N.; Shimaa, M. G.; El, M. A. and Hazem, A. (2022). Multivariate analysis of plankton variability and water pollution in two highly dynamic sites , southeastern Mediterranean (Egyptian coast). Arab. J. Geosci.1–23.

Huang, H.; Yu, Y. J. and Wang, X. D. (2004). Pollution of heavy metals in surface sediments from Huaihe River (Jiangsu Section) and its assessment of potential ecological risk. Environ. Pollut. Control, 26 (3):115–118.

Huang, K. M., and Lin, S. (2003). Consequences and implication of heavy metal spatial variations in sediments of the Keelung River drainage basin, Taiwan. Chemo- Sph., 53 (9):1113–1121.

IAEA. (2004). Soil Sampling for Environmental Contaminants; International Atomic Energy Agency: Vienna, Austria,.

Ingram, R. L. (1971). Sieve analysis. In Procedures in Sedimentary Petrology; Carver, R.E., Ed.; Jhon Wiley Intersciences: New York, NY, USA.

Jackson, M. L. (1962). Soil chemical analysis constable and Co. LTD. London.

Khaled, A.; El Nemr, A. and Sikaily, A. (2006) An assessment of heavy-metal contamination in surface sediments of the Suez Gulf using geoaccumulation indexes and statistical analysis, 22 (3): 239–252.

Mishra, R. R.; Rath, B. and Thatoi, H. (2008). Water Quality Assessment of Aquaculture Ponds Located in Bhitarkanika Mangrove Ecosystem, Orissa, India. Turkish J. Fish. Aquat. Sci., 8 :71–77.

Molnia, B. F. (1974). A rapid and accurate method for the analysis of calcium carbonate in small samples. J. Sediment. Petrol., 44 (2): 589–590.

Mora, S., Sheikholeslami, M. R., Wyse, E., Azemard, S. and Cassi, R. de. (2004). An assessment of metal contamination in coastal sediments of the Caspian Sea. Mar. Pollut. Bull., 48: 61–77.

Muller, G. (1969) Index of geo-accumulation in sediments of the Rhine River. 2(3):, 2 (3), 108-118.

Oregioni, B. and Aston, S. R. (1984). The determination of selected trace metals in marine sediments by Flameless/ Flam-Atomic absorption spectrophotometry. IAEA Monaco Laboratory Internal Report. on Water and Sediment Quality of Al-Burullus Lake, Egypt. Water Resources Management II, p.11.

Piper, C. S. (1947) .Soil and Plant analysis. Intersci. Publ. Inc. New York.

Praveena, S. M .; Radojevic, M. and Abdullah, M. H. (2007). The assessment of mangrove sediment quality in mengkabong lagoon: an index analysis approach. Int. J. Environ. Sci. Educ., 2 (3) :60–68.

USEPA.(1986). Quality Criteria for Water. United States Environmental Protection

Agency office of Water Regulations and Standards. DC, 20460.

Seshan, B. R. R.; Natesan, U and Deepthi, K. (2010). Geochemical and statistical approach for evaluation of heavy metal pollution in core sediments in southeast coast of India. Int. J. Environ. Sci. Tech., 7 (2):291–306.

Tomlinson, D. C.; Wilson, D. J.; Harris, C. R. and Jeffrey, D. W. (1980). Problem in assessment of heavy metals in estuaries and the formation of pollution index. Helgol. Wiss. Meeresunlter, 33: 566-575.

Turekian, K. K. and Wedepohl, K. H. (1961). Distribution of the elements in some major units of the earth's crust. Geo. Soc. Am. Bull., 72 (2): 175–192.

WHO. (2004). Guidelines for Drinking-Water Quality, Health Criteria and Other Supporting Information; 3rd ed., Vol. 2., Geneva, World Heath O rganization.

Halim,Y. (1984). Plankton of the Red Sea and the Arabian Gulf, Deep Sea Research Part A. *Oceanogr*. *Res. Pap.*, 31 (6): 969–982.