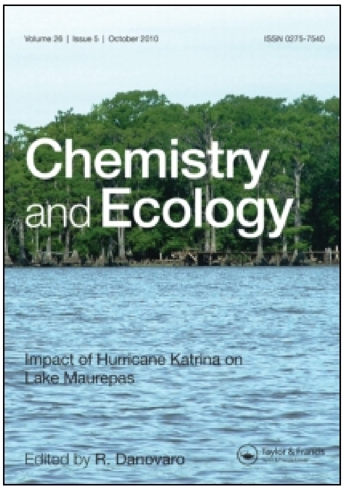

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An assessment of heavy-metal contamination in surface sediments of the Suez Gulf using geoaccumulation indexes and statistical analysis

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An assessment of heavy-metal contamination in surface sediments of the Suez Gulf using geoaccumulation indexes and statistical analysis

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An assessment of marine pollution due to metals was made in the Suez Gulf based on surface costal sediment collected from 18 locations along the Gulf. The samples were dried and acid-digested, and the metal contents (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) were determined using a flame atomic absorption spectrophotometer (air–acetylene) with deuterium background correction. An evaluation of the heavy-metal pollution status of the Gulf was carried out using enrichment factors (EF) and geo-accumulation Indexes (I_{geo}). Also, heavy-metal concentrations in Suez Gulf sediments were evaluated using the Effect Range-Low (ERL) and the Effect Range-Median (ERM). The results of a Spearman correlation and factor and cluster analysis of the heavy metals analysed in the collected sediment were discussed. The main source of contamination is offshore oil field and industrial wastes, which arise due to the ineffective and inefficient operation equipments, illegal discharge and lack of supervision, and prosecution of offenders.

Keywords: Suez Gulf; Heavy metals; Surface sediment; Pollution; Geoaccumulation indexes; Enrichment factors

1. Introduction

The Suez Gulf is the most polluted area in the Red Sea. Its main problem arises from the ship's oil and refuse, several industrial (oil refineries, marketing, storage and piping, fertilizers and chemicals, cement, thermal electric stations, ceramics, steel, shipyard, edible oils, and fibreglass) and domestic drains in the northern part as well as tourism activities in the south part [1–5]. In addition, the northern area of the Gulf is receiving a heavy load of waste water from industrial and sewage effluents. The main industries in this area are petrochemicals, fertilizers, and power stations. The amounts of constituents (ton yr^{-1}) conveyed to northern area of the Gulf are NH_4 (125), NO_2 (1.09), NO_3 (3.57), and PO_4 (70.65) [6]. The middle and southern parts of the Gulf are under stress from extensive inshore and offshore oil-production operations. The cumulative productions from the Gulf oil fields are more than 250 million

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barrels per year, whereas the human impact on the eastern (Sinai Peninsula) and southern sides (El-Tour City) are still insignificant due to the low population there. The sediments of the Suez Gulf comprise disintegration products of coral-reef framework builder (local production), rock fragments, quartz and feldspars, as well as carbonate pellets [7, 8].

Heavy metals are a group of contaminants of high ecological significance, since they are not removed from water as a result of self-purification but accumulate in suspended particulates and sediment, and hence enter the food chain. Metals may mobilize as a result of natural processes (e.g. weathering and erosion of geological formations) as well as by anthropogenic activity [9]. The large inputs of metals of natural origin reach coastal areas from estuaries in the form of particulate material and are mainly chemically bound to aluminosilicates, and thus are not readily bioavailable. On the other hand, metals of anthropogenic origin are more loosely bound to sediments and are therefore more readily available to organisms under variations of some physical–chemical and chemical parameters like oxidative-reductive potential, dissolved oxygen, pH, organic, and inorganic carbon content [10].

Analysis of bottom sediments, which accumulate most of the heavy-metal pollutants, enable us to gain an integrated picture of the contamination because the level of metals in bottom sediments is the result of prolonged sedimentation processes and does not undergo sudden changes because of altering external conditions [11, 12]. It has long been demonstrated that sediments can adsorb persistent and toxic chemicals to levels many times higher than water column concentrations [13]; hence, bottom sediments can serve as a reservoir for heavy metals and therefore deserve special consideration in the planning and design of aquatic-pollution research studies [14].

The purpose of this study was to determine the concentrations of Cd, Co, Cr, Cu, Fe, Mn, Ni, Pd, and Zn in surface sediments collected from 18 locations of the Suez Gulf. These locations receive large amounts of contaminated wastes from mining, industrial, and oil-refinery activities. The surface layer was chosen where this layer controls the exchange of metals between sediments and water, as well as constituting a reserve of metals to which benthic organisms are exposed. Moreover, using the surface sediment as a contamination indicator for studying of the Suez Gulf environmental health by certain mathematical equations such as geoaccumulation index and enrichment factors will enable us to obtain a good evaluation of the pollution status of the Gulf.

2. Materials and methods

2.1 *Sampling*

Sampling locations along the Suez Gulf were selected to cover the expected polluted area due to industrial and other activities [4, 5] (figure 1). A total of 18 surface sea sediments were collected during the last week of March and first week of April in 1999 from a depth of 8–15 m with a 0.025 m^2 Van-Veen grab sampler. Only grabs that had achieved adequate penetration (two-thirds of the total volume) to collect the first 5 cm of the sediment and that showed no evidence of leakage or surface disturbance were retained and transferred to a cooler. When sufficient sediment had been collected from a particular station, the contents of the cooler were homogenized with a Teflon spoon until no colour or textural differences could be detected. Then, the chilled coolers (−4 °C) were transported to the laboratory 8–15 h after collection. Samples were transferred into labelled polyethylene bags and stored in the laboratory at −20 °C until analysis. The sediment samples were dried in an oven at 105 °C to constant weight, sieved, and subsequently ground in an agate mortar.

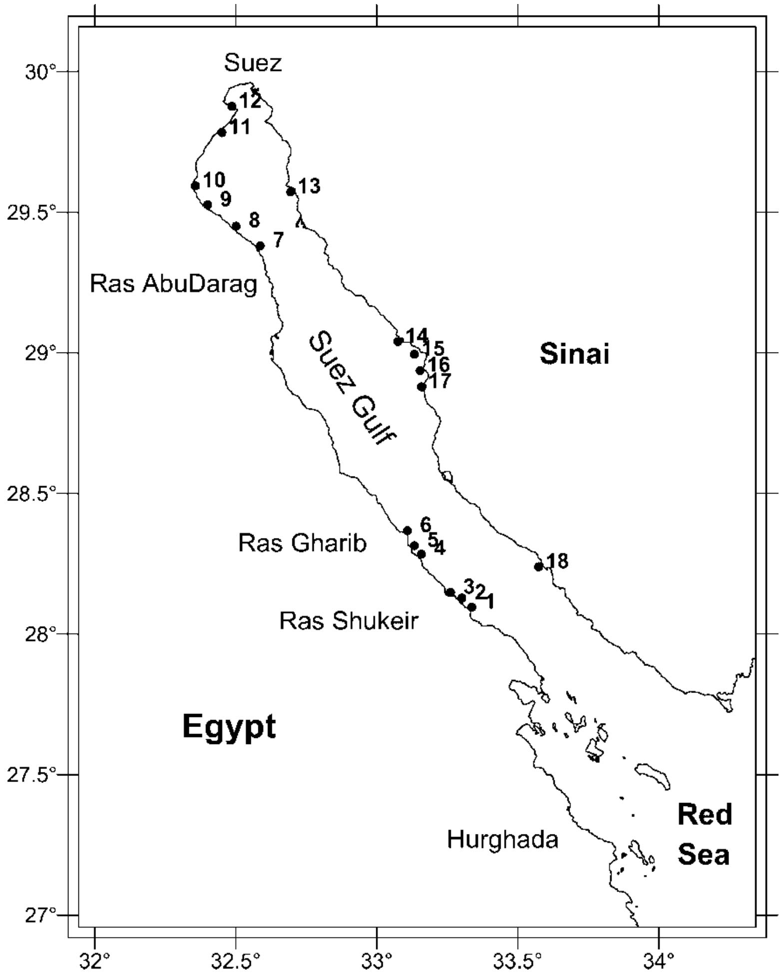

Figure 1. Locations of the samples collected from the Suez Gulf, Red Sea.

2.2 *Grain-size analysis*

Grain-size analysis was carried out using the conventional method, about 30 g of washed quartered dried samples were placed in the topmost sieve, and the entire column of sieves was shaken on a mechanical shaker 'Betriebsanleitung vibration testing sieve mechanical machine Thyr 2' for 20 min. The sieve meshes give glass intervals of 2, 1, 0.5, 0.2, 0.125, and 0.063 mm (sand fraction 0.063–0.200 mm and mud fraction <0.063 mm) [15].

2.3 *Determination of heavy metals*

Total heavy metals in bottom sediments were determined using the method described elsewhere [5, 16, 17]. Dry sediment (0.2 g) was completely digested in a polytetrafluoroethylene vessel using a mixture of HNO_3, HF, and $HCLO_4$ (3 : 2 : 1 v/v, 10 ml) (triplicate digestions were made for each sample). The final solution was diluted to 25 ml with distilled deionized water in a polytetrafluoroethylene flask and filtered through filter paper (Schleicher & Schüll

Table 1. Heavy-metal concentrations ($\mu g\, g^{-1}$ dry wt.) in reference materials analysed together with Suez Gulf sediments.

Element	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Certified values	0.11	13.6	77.2	32.7	27.1	12.1	56.1	22.8	74.8
Found values	0.107	12.33	75.39	31.19	26.45	11.46	53.90	21.27	71.38
Recovery (%)	97.27	90.64	97.65	95.39	97.61	94.73	96.08	93.29	95.43

Folded Filters, S&S 5951/2) into polyethylene bottles. All digested solutions were analysed in triplicate using an atomic absorption spectrophotometer (Spectr AA-10 plus Varian) working with an air–acetylene flame and D2 background correction at optimum instrument operating conditions recommended by the manufacturer. The results were expressed in $\mu g\, g^{-1}$ dry weight. The absorption wavelength and detection limits were as follows: 228.8 nm and 0.006 $\mu g\, g^{-1}$ for Cd; 240.7 nm and 0.009 $\mu g\, g^{-1}$ for Co; 357.9 nm and 0.009 $\mu g\, g^{-1}$ for Cr; 324.7 nm and 0.008 $\mu g\, g^{-1}$ for Cu; 248.3 nm and 0.007 $\mu g\, g^{-1}$ for Fe; 279.5 nm and 0.006 $\mu g\, g^{-1}$ for Mn; 232.0 nm and 0.009 $\mu g\, g^{-1}$ for Ni; 217.0 nm and 0.01 $\mu g\, g^{-1}$ for Pb; 213.9 nm and 0.004 $\mu g\, g^{-1}$ for Zn, respectively.

2.4 *Quality assurance*

To control accuracy and to determine the uncertainty of heavy-metal determination, every extraction batch of six samples included a blank extraction and reference material (SD-M-2/TM, marine sediments which was totally digested by $HNO_3/HF/HClO_4$ solution). Analytical results of the quality-control samples indicated a satisfactory performance of heavy-metal determinations lying within the range of certified values with 90.4–97.5% recovery for all metals studied (table 1). To prevent contamination, all plastic laboratory equipment used was previously washed in diluted nitric acid and deionized water; also, all chemicals used in the experiment were from Merck and of high purity.

2.5 *Estimation of enrichment factor (EF)*

For a better estimation of anthropogenic input, an enrichment factor (EF) was calculated for each metal by dividing its ratio to the normalizing element by the same ratio found in the chosen baseline. The EFs for each element were calculated from the formula [5, 18]:

$$\mathrm{EF} = \frac{(\mathrm{M/Fe})\mathrm{sample}}{(\mathrm{M/Fe})\mathrm{crust}}.$$

The values for the earth's crust are from Martin and Melbeck [19] and represent the average composition of the surficial rocks exposed to weathering. EFs around 1.0 indicate that the element in sediment is originated predominantly from lithogenous material, whereas EFs that are considerably higher than 1.0 indicate that the element is of anthropogenic origin [20].

2.6 *Statistical analysis*

Principal-component analysis, Spearman (non-parametric) rank order correlations, and factor analysis as a Varimax normalization rotated were performed using the SPSS program version 10.0 for Windows. Statistical analyses were performed on an Intel Pentium IV 2.8 GHz computer.

3. Results and discussion

3.1 *Sediment classification*

Table 2 reports the grain-size composition of the sampled stations, in particular the percentage of sand (0.063–2 mm) and mud (silt and clay, <0.063 mm). Sediments are generally sandy, except stations 10 and 18 which are medium silt. Stations 2, 5, 6, 8, 9, 13, 14, 15, and 17 generally have fine sand, and stations 1, 4, 7, 11, 12, and 16 have a medium-sized sand fraction, while station 3 has coarse sand.

3.2 *Heavy-metal distribution in sediments*

The concentrations of the heavy metals investigated (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn) in the sediment samples collected from Suez Gulf are summarized in table 3. The mean concentration of heavy metals in sediments of Suez Gulf represented the next decreasing order Fe > Mn > Zn > Pb > Co > Ni > Cu > Cr > Cd. Cadmium, chromium, and copper showed the lowest concentrations at most stations, which is in agreement with the concentrations that we reported previously for the total and labile heavy metals in sand and mud sediments of the Suez Gulf [3, 5].

Cadmium concentrations in Suez Gulf sediments ranged between 6 and 24.8 $\mu g\,g^{-1}$ dry weight. However, 66.7% of studied locations have concentration values $< 10\,\mu g\,g^{-1}$ and 27.8% $< 20\,\mu g\,g^{-1}$, while 5.6% have concentration values $> 20\,\mu g\,g^{-1}$ dry weight. The mean concentration of Cd in the present study was higher than that reported in Swan Lake sediments of Galveston Bay [21] and for the south-west coast of Spain [22] but within the range observed for the River Danube [23]. The concentration of Cd in this study showed values higher than both of the Effect Range Low (ERL) and the Effect Range Median (ERM) values [24, 25] for stations 1, 2, 3, 4, 5, 12, and 17 (table 3).

The lowest concentration of cobalt in sediments was recorded at station 6 (22.5 $\mu g\,g^{-1}$ dry wt.) while the highest concentration was recorded at station 5 (525.4 $\mu g\,g^{-1}$ dry wt.). However,

Table 2. Sample locations and percentage grain-size distribution of Suez Gulf sediment samples.

Station no.	Location E	Location N	Sand (%)	Silt (%)	Clay (%)	Sediment type
1	33.337	28.095	97.6	2.0	0.4	Medium sand
2	33.302	28.128	98.9	1.2	0.0	Fine sand
3	33.262	28.148	98.5	1.0	0.4	Coarse sand
4	33.158	28.284	100.0	0.0	0.0	Medium sand
5	33.133	28.314	100.0	0.0	0.0	Fine sand
6	33.108	28.367	99.1	0.7	0.2	Fine sand
7	32.587	29.380	100.0	0.0	0.0	Medium sand
8	32.501	29.450	99.0	1.0	0.0	Fine sand
9	32.400	29.526	99.0	0.9	0.1	Fine sand
10	32.357	29.594	48.5	12.5	39.1	Medium silt
11	32.451	29.783	98.3	1.0	0.7	Medium sand
12	32.486	29.877	86.7	7.4	5.8	Medium sand
13	32.695	29.572	98.6	1.1	0.2	Fine sand
14	33.075	29.040	82.7	7.2	8.1	Fine sand
15	33.133	28.995	96.5	1.5	1.8	Fine sand
16	33.154	28.937	98.2	0.7	1.0	Medium sand
17	33.158	28.879	53.1	24.7	22.2	Fine sand
18	33.574	28.239	21.8	54.1	24.1	Medium silt

Table 3. Concentrations of heavy metals ($\mu g\, g^{-1}$ dry weight) in Suez Gulf sediment samples.

Station no.	Concentration of heavy metals ($\mu g\, g^{-1}$ dry weight) Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	MPI
1	10.81	34.38	86.02	133.95	13952.4	758.4	89.86	48.49	136.31	144.17
2	14.52	31.37	25.08	9.36	1125.1	23.5	73.58	89.2	85.02	48.82
3	17.07	35.86	24.98	7.26	1252.1	48.0	60.84	53.49	73.35	48.87
4	24.77	51.35	70.18	99.93	9610.1	124.9	80.01	86.2	161.07	131.67
5	12.08	525.37	22.85	33.18	1278.9	40.7	76.87	75.45	40.55	72.99
6	8.57	22.52	31.98	22.54	216.3	17.1	61.12	66.55	45.61	35.75
7	6.27	75.9	30.01	16.78	422.4	48.5	96.7	49.67	353.71	58.76
8	6.25	58.16	38.04	11.02	670.2	74.9	47.56	62.8	96.16	50.66
9	7.59	23.66	28.98	24.52	2331.1	93.9	59.08	35.55	72.9	54.55
10	6.08	66.24	61.19	388.36	3593.7	114.2	54.16	79.72	212.69	115.32
11	7.99	41.8	18.58	21.38	1341.5	37.8	60.95	91.74	92.61	53.31
12	10.05	34.08	21.09	96.63	1270.2	48.7	60.16	86.39	143.72	68.29
13	8.8	49.43	16.07	58.42	1714.1	176.2	75.02	99.81	84.92	75.36
14	6.7	39.62	24.81	26	12 428.3	1616.0	59.17	71.48	74.84	100.95
15	7.89	36.97	16.08	24.8	726.0	136.8	44.86	79.28	75.73	52.65
16	9.56	44.83	16.07	15.89	333.1	177.3	76.97	89.67	33.46	48.53
17	9.91	53.08	19	18.99	3671.9	117.5	77.84	83.35	60.92	68.3
18	6.79	38.83	17.1	22.02	8690.1	162.4	53.1	80.72	58.85	68.98
Mean	10.09	70.19	31.56	57.28	3590.4	212.0	67.1	73.86	105.69	72.11
Min	6.08	22.52	16.07	7.26	216.3	17.1	44.86	35.55	33.46	35.75
Max	24.77	525.37	86.02	388.36	13 952.4	1616.0	96.7	99.81	353.71	144.17
ERL	1.25	ND	81	34	ND	ND	20.9	46.7	150	ND
ERM	9.65	ND	370	270	ND	ND	51.6	218	410	ND

Note: ND no data available.

half of the studied locations showed Co concentrations within the range of 20–40 $\mu g\, g^{-1}$ dry wt. The concentration of Co in the present study is higher than that reported for the Galician Ria sediments in NW Spain (4–12 $\mu g\, g^{-1}$ dry wt.) [26].

Chromium released by the electroplating, steel manufacturing, leather tanning, and textile industries is the main source for water contamination by chromium. Hexavalent chromium is widely known for its toxic effects on humans and animals [27–29], compared with trivalent chromium, which is considered to be an essential trace element [30]. The mean concentration of Cr in the present work was 31.5 $\mu g\, g^{-1}$ dry wt., and the highest value was recorded at station 1 (86 $\mu g\, g^{-1}$ dry wt.). However, 72% of the Cr concentrations results obtained were within the range of 10–30 $\mu g\, g^{-1}$ dry wt. Most of the studied locations showed Cr concentrations lower than the ERL (81 $\mu g\, g^{-1}$ dry wt.) except for station 1, which was higher than the ERL and lower than the ERM value (370 $\mu g\, g^{-1}$ dry wt.). The average concentration of Cr in the present study is lower than its concentrations in Danube river sediments ($64 \pm 6.5\, \mu g\, g^{-1}$ dry wt.) [23], comparable with that found in Lake Kariba, Zimbabwe ($29.3 \pm 1.6\, \mu g\, g^{-1}$ dry wt.) [31] and south-west coast of Spain [22], within the range reported for Galician Ria sediment (north-west Spain) [26], but higher than the mean concentration of Gulf Lake Victoria, Tanzania [14].

A very low concentration of copper is essential for organisms, and several copper-containing proteins have been identified in biological systems [32]. Copper can exist in aquatic environments in three broad categories: particulate, colloidal, and soluble. It sorbs rapidly to sediments, and its desorption into the bulk water depends on pH, salinity, and the presence of natural and or synthetic chelating agents [33]. In this study, Cu concentrations ranged from 7.3 $\mu g\, g^{-1}$ dry wt. at station 3 to 388.4 $\mu g\, g^{-1}$ dry wt. at station 10. The Cu concentrations in 72% of the studied locations are lower than the ERL (34 $\mu g\, g^{-1}$ dry wt.), and 22.2% of the studied locations are lower than ERM (270 $\mu g\, g^{-1}$ dry wt.), while only station 3 shows a Cu concentration higher than ERM. The average Cu concentration in the present study was lower than that recorded in the bottom sediment of the Rybnik Reservoir in Poland (451.74 $\mu g\, g^{-1}$ dry wt.) [34], while it is comparable with the concentration range obtained for sediment from Swan Lake, River Danube [21], Northern China Bay [23], and the south-west coast of Spain [22].

Fe concentrations of in the sediment collected from Suez Gulf ranged between 216.3 and 13 952.4, and the average value was 3590.4 $\mu g\, g^{-1}$ dry wt. The mean concentration of Fe in the present study was about 10% of the value recorded for the Rybnik Reservoir in Poland [34] but comparable with that recorded along the Spanish coast [26, 22] and Ivory Coast of West Africa [35].

Manganese and its compounds can exist as solids in the sediment and as solutes or small particles in water. The tendency of soluble manganese compounds to adsorb to sediments can be highly variable, depending mainly on the cations exchange capacity and the organic composition [36]. Station 14 recorded the highest concentration value of Mn, while station 6 showed the lower value (table 3). The Mn concentration in the present work was much lower than that obtained for the bottom sediment of the Rybnik Reservoir, Poland [11] but comparable with that obtained for Pagassitikos Gulf sediment, Greece [37] and with that reported for the Spain coast sediments [22, 26].

Most nickel is used for the production of stainless steel and other nickel alloys with a high corrosion and temperature resistance [38]. Nickel can enter surface waters from natural sources such as particulate matter in rainwater, through the dissolution of bedrock minerals, and soil phases [39]. Also, it may be deposited in the sediment by precipitation, complexation, and adsorption on clay particles, and via uptake by biota. The release of nickel from sediments may occur as a result of microbial activity and changes in physical and chemical parameters such as pH, ionic strength, and sorption processes [40]. The mean concentration of nickel (44.9 $\mu g\, g^{-1}$ dry wt.) belonged to the range of the most frequent values, *i.e.* 40–100 $\mu g\, g^{-1}$ dry wt. The average concentration of Ni in the present study was lower than that recorded in the bottom sediment of the Rybnik Reservoir, Poland [11], while it was higher than that reported for the Spanish coast sediments [22, 26]. All sites under investigation showed Ni concentrations higher than the ERM (51.6 $\mu g\, g^{-1}$ dry wt.) except stations 8 and 15.

Lead is one of the most abundant toxic metals in the Earth's crust. Ten to 15% of lead is absorbed orally, of which 90% is distributed to the bones [41]. Lead has been used since prehistoric times and has become mobilized and widely distributed in the environment [42]. The main sources of lead inputs to water were the manufacturing industry, smelting and refining of metals, sewage sludge, and domestic waste water [43]. Sorption of lead by sediments is correlated with organic content, grain size, and anthropogenic pollution [44]. In the present study, the concentration of lead fluctuated between 35.6 $\mu g\, g^{-1}$ dry wt. at station 9 and 99.8 $\mu g\, g^{-1}$ dry wt. at station 13. Of the locations studied, 44.5% have Pb concentrations within the range of 80–100 $\mu g\, g^{-1}$ dry wt., indicating that the Suez Gulf sediments have considerable contamination with Pb. However, its Pb concentrations were comparable with that recorded for Galveston Bay in USA (23.7–129.0 $\mu g\, g^{-1}$ dry wt.) [21] and Spanish coast [22]. The concentrations of lead at all studied locations were higher than the ERL (46.7 $\mu g\, g^{-1}$ dry wt.) but lower than ERM (218 $\mu g\, g^{-1}$ dry wt.), except station 15 which exhibited a concentration value lower than the ERL value.

The surface sediment of the Suez Gulf in the present study was moderately contaminated with Zn. About half of the locations studied showed concentration values within the ranges of 60–100 $\mu g\, g^{-1}$, and 29% of the studied locations recorded concentration values $> 100\ \mu g\, g^{-1}$ dry wt. In the present study, all of concentration values were lower than the ERL (150 $\mu g\, g^{-1}$ dry wt.), except stations 10, 7, and 4, which were between the ERL and ERM values.

3.3 *Geoaccumulation index*

Geoaccumulation index (I_{geo}) allows the contamination of the investigated sediment with organic and inorganic pollutants to be determined by comparing present concentrations with pre-industrial levels. Concentrations of geochemical background are multiplied each time by 1.5 in order to allow content fluctuations of a given substance in the environment as well as very small anthropogenic influences. Values of geoaccumulation index can be defined as follows:

$$I_{\text{geo}} = \log_2[C_n/(1.5 \times B_n)],$$

where C_n is the concentration of the examined element in the examined bottom sediment, and B_n is the geochemical background of a given element. The classification of sediments depending on the I_{geo} value is shown in table 4. The I_{geo} values calculated for heavy-metal concentrations in Suez Gulf surface sediments were represented in table 5. The main I_{geo} value was <0 for Fe (-3.47) and Mn (-1.77), indicating that the studied locations from Suez Gulf were uncontaminated with these two elements, while the main I_{geo} values for Cr, Cu, and Zn were <2, which indicated a moderately contaminated of the Suez Gulf sediments with these elements in the following order Zn $>$ Cu $>$ Co. Cd concentrations showed a main I_{geo} value <3, which means that the Suez Gulf sediments were moderately to strongly contaminated with Cd. The main I_{geo} values for Ni and Pb were 3.95 and 3.59, respectively, indicating a strong contamination of surface sediments of the Suez Gulf with Ni and Pb due to its input from cement manufacture, oil refineries, and thermal electricity stations as well as the sewage discharges [45]. The main I_{geo} values in the present work were higher than that recorded in the sediment of the Rybnik Reservoir, Poland [11].

3.4 *Metal-pollution index*

The overall metal contents of sediments at the sites investigated in this study were compared using the metal-pollution index (MPI) calculated according to Usero *et al.* [47] with the formula:

$$\text{MPI} = (Cf_1 \times Cf_2 \times \cdots \times Cf_n)^{1/n},$$

where Cf_n is the concentration of the metal n in the sample.

The MPI values of the nine heavy metals in the Suez Gulf sediments of the area under investigation are summarized in table 3. The lowest MPI value was recorded at station 6, while the highest value was found at station 1, which indicated that the lowest polluted area was at station 6, while the highest polluted area compared with the other studied locations was at station 1. This might be reasonable, because station 1 was very near to Suez City and the industrial activities area.

Table 4. I_{geo} classification (Müller 1979).

I_{geo}	I_{geo} class	Designation of sediment quality
>5	6	Extremely contaminated
4–5	5	Strongly to extremely contaminated
3–4	4	Strongly contaminated
2–3	3	Moderately to strongly contaminated
1–2	2	Moderately contaminated
0–1	1	Uncontaminated to moderately contaminated
<0	0	Uncontaminated

Table 5. Geoaccumulation indexes of heavy metals in Suez Gulf sediments.

	Geoaccumulation (I_{geo}) of heavy metals							
Station no.	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
1	1.92	2.87	3.30	−0.25	1.30	4.73	3.30	2.64
2	1.80	1.13	−0.54	−3.82	−3.69	4.53	4.25	1.99
3	1.99	1.11	−0.91	−3.69	−2.67	4.23	3.49	1.77
4	2.51	2.64	2.89	−0.67	−1.26	4.74	4.26	2.94
5	5.87	1.02	1.30	−3.58	−2.88	4.68	4.07	0.95
6	1.32	1.48	0.73	−6.19	−4.15	4.28	3.83	1.10
7	3.08	1.42	0.31	−5.18	−2.63	5.01	3.46	4.07
8	2.69	1.73	−0.30	−4.57	−2.02	3.91	3.74	2.17
9	1.39	1.34	0.86	−2.76	−1.69	4.23	2.93	1.77
10	2.65	1.51	4.55	−3.60	−2.06	2.25	2.55	2.41
11	2.21	0.68	0.65	−3.60	−3.02	4.22	4.26	2.10
12	1.86	0.60	2.76	−4.15	−2.83	3.54	3.65	2.47
13	2.45	0.48	2.11	−3.23	−0.79	4.54	4.39	1.98
14	2.06	0.75	0.84	−1.00	2.17	3.34	3.23	1.45
15	2.02	0.43	0.86	−4.57	−1.19	3.65	3.95	1.76
16	2.31	0.47	0.22	−5.61	−0.79	4.55	4.22	0.63
17	2.35	−0.12	0.22	−3.48	−1.97	2.88	2.70	0.67
18	1.82	−0.53	0.33	−2.59	−1.71	1.93	2.29	0.36
Mean	2.35	1.06	1.12	−3.47	−1.77	3.96	3.59	1.85

3.5 *Enrichment factors*

Table 6 shows the EF values calculated for the heavy-metal concentrations in the present study. The EF values were varied from metal to metal and location to location, and the percentage of studied locations with EF > 2 in sediments of Suez Gulf was represented in figure 2, which showed that the sediments of Suez Gulf can be regarded as unpolluted with Mn and Cr. On the other hand, a serious contamination of the Suez Gulf may be discussed for Cd, Co, Pb,

Table 6. Enrichment factors for heavy metals in Suez Gulf sediments.

	Enrichment factors (EFs) for heavy metals							
Station no.	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn
1	13.94	0.68	0.31	1.08	0.27	0.47	0.78	0.28
2	232.36	7.72	1.13	0.94	0.1	4.81	17.84	2.14
3	245.34	7.93	1.01	0.65	0.19	3.57	9.61	1.66
4	46.39	1.48	0.37	1.17	0.06	0.61	2.02	0.48
5	170.02	113.76	0.91	2.92	0.16	4.42	13.27	0.9
6	712.84	28.84	7.5	11.73	0.4	20.76	69.22	5.98
7	267.19	49.76	3.6	4.47	0.57	16.82	26.46	23.74
8	167.96	24.03	2.88	1.85	0.56	5.21	21.08	4.07
9	58.57	2.81	0.63	1.18	0.2	1.86	3.43	0.89
10	30.44	5.1	0.86	12.16	0.16	1.11	4.99	1.68
11	107.21	8.63	0.7	1.79	0.14	3.34	15.39	1.96
12	142.47	7.43	0.84	8.56	0.19	3.48	15.3	3.21
13	92.41	7.99	0.48	3.83	0.51	3.22	13.1	1.4
14	9.7	0.88	0.1	0.24	0.65	0.35	1.29	0.17
15	195.62	14.1	1.12	3.84	0.94	4.54	24.57	2.96
16	516.62	37.27	2.45	5.37	2.66	16.98	60.57	2.85
17	48.58	4	0.26	0.58	0.16	1.56	5.11	0.47
18	14.06	1.24	0.1	0.29	0.09	0.45	2.09	0.19
Mean	170.65	17.98	1.4	3.48	0.45	5.2	17.01	3.06
Min	9.7	0.68	0.1	0.24	0.06	0.35	0.78	0.17
Max	712.84	113.76	7.5	12.16	2.66	20.76	69.22	23.74

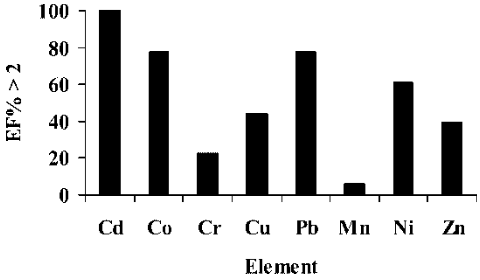

Figure 2. Percentage of sampling stations with EF > 2 in sediments of the Suez Gulf.

and Ni because the concentrations of these elements were higher than twice their background in 100, 77.8, 77.8, and 61% of the investigated samples.

3.6 *Statistical analysis*

Spearman (non-parametric) rank order correlations for studied heavy-metal concentrations in sediments of Suez Gulf were represented in table 7. A significant positive correlation ($P < 0.05$) exists between Cd and Ni ($r = 0.52$), Cr and Zn ($r = 0.51$), Cu and Fe ($r = 0.58$), and Fe and Mn ($r = 0.54$). In addition, a significant negative correlation ($P = 0.01$) was observed between Cr and Pb ($r = -0.60$). No element was correlated with Co in this study. Weak correlations between the studied elements may prove the presence of different sources for the input of heavy metals to the Suez Gulf.

A multivariate analysis (principal-component analysis, PCA) on the data matrix obtained from heavy-metal analysis of sediments of Suez Gulf was used. In this way, the number of variables under investigation was reduced, and interelement associations could be assessed in detail [5, 48, 49]. R-mode factor analysis with varimax rotation was applied to the heavy-metal concentrations in sediment. A five-factor model explaining 85.43% of total variance

Table 7. Spearman (non-parametric) rank order correlations for heavy metals in Suez Gulf sediments.

		Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Cd	*r*	1.00								
	P	0.00								
Co	*r*	−0.24	1.00							
	P	0.34	0.00							
Cr	*r*	−0.01	−0.01	1.00						
	P	0.96	0.96	0.00						
Cu	*r*	−0.01	0.08	0.23	1.00					
	P	0.98	0.77	0.37	0.00					
Fe	*r*	0.08	0.06	0.17	**0.58**	1.00				
	P	0.75	0.81	0.50	0.01	0.00				
Mn	*r*	−0.17	0.12	−0.20	0.39	**0.54**	1.00			
	P	0.51	0.63	0.43	0.11	0.02	0.00			
Ni	*r*	**0.52**	0.24	0.16	0.03	0.06	−0.01	1.00		
	P	0.03	0.35	0.52	0.89	0.82	0.98	0.00		
Pb	*r*	0.25	0.13	**−0.60**	0.04	−0.01	0.05	0.09	1.00	
	P	0.33	0.62	0.01	0.89	0.97	0.84	0.73	0.00	
Zn	*r*	−0.16	0.21	**0.51**	0.32	0.17	−0.02	0.09	−0.03	1.00
	P	0.52	0.41	0.03	0.19	0.51	0.93	0.74	0.90	0.00

Note: Correlation is significant at the $P < 0.05$ level.

Table 8. Varimax normalization rotated factor loadings for five factors obtained for Suez Gulf sediments.

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Cd	0.008	0.007	**0.903**	−0.236	−0.042
Co	−0.072	−0.035	0.063	0.056	**0.973**
Cr	0.381	**0.700**	0.393	0.241	−0.086
Cu	0.071	**0.957**	−0.123	−0.132	0.023
Fe	**0.903**	0.227	0.226	0.034	−0.085
Mn	**0.918**	−0.048	−0.155	0.083	−0.013
Ni	0.024	0.057	**0.700**	0.451	0.302
Pb	−0.173	0.049	0.104	−0.824	0.052
Zn	−0.204	0.596	0.114	0.604	−0.081
Variance (%)	20.96	20.21	17.00	15.44	11.82
CV (%)	20.96	41.17	58.17	73.61	85.43

Note: Data were corrected prior to statistical analysis ($n = 99$). CV: cumulative variance; bold numbers indicate a positive correlation, whereas italic values indicate a negative correlation. Extraction method: principal-component analysis; rotation method: varimax with Kaiser normalization; marked loadings are>0.70.

was adapted for surface sediments of the Suez Gulf (table 8). Factor 1, which described 20.96% of the variance, has a high positive factor loading for Fe (0.90) and Mn (0.92). These elements are known to be associated with hydrothermal processes, and so will be considered ‘hydrothermal factors’. Hydrothermal fluids may have been responsible for the accumulation of metal oxides. Factor 2 (20.21% of the data variance) has a high positive factor loading for Cr (0.70) and Cu (0.96), and moderate positive factor loading for Zn (0.60). Zinc is associated with the sapropelic factor and so will be considered a ‘slightly sapropelic factor’. Factor 3, which described 17.0% of the variance, has a high positive factor loading for Cd (0.90) and Ni (0.70). These two elements inter the Suez Gulf mainly from industrial activities and so will be considered ‘industrial factors’. Factor 4 (15.44% of the data variance) has a high negative factor loading for Pb (−0.82) and a moderate positive factor loading for Zn (0.60). Pb is incorporated into terrigenous alumino-silicates, and Zn is associated with the sapropelic factor; therefore, it will be considered a ‘sapropelic-terrigenous alumino-silicate factor’. Factor 5 (11.82% of the data variance) represented a high positive factor loading for Co (0.97).

The cluster analysis was based on nine variables at 18 stations using the Education distance measure (figures 3 and 4). Figure 3, the dendrogram obtained by average linkage (between

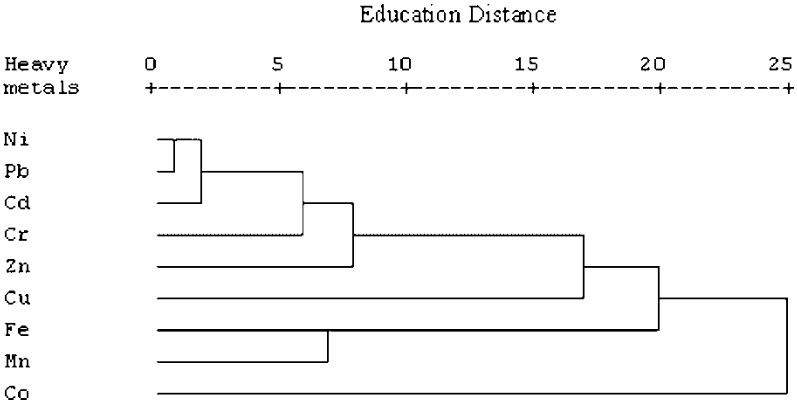

Figure 3. Dendrogram for hierarchical cluster analysis of nine heavy-metals concentration in Suez Gulf sediments.

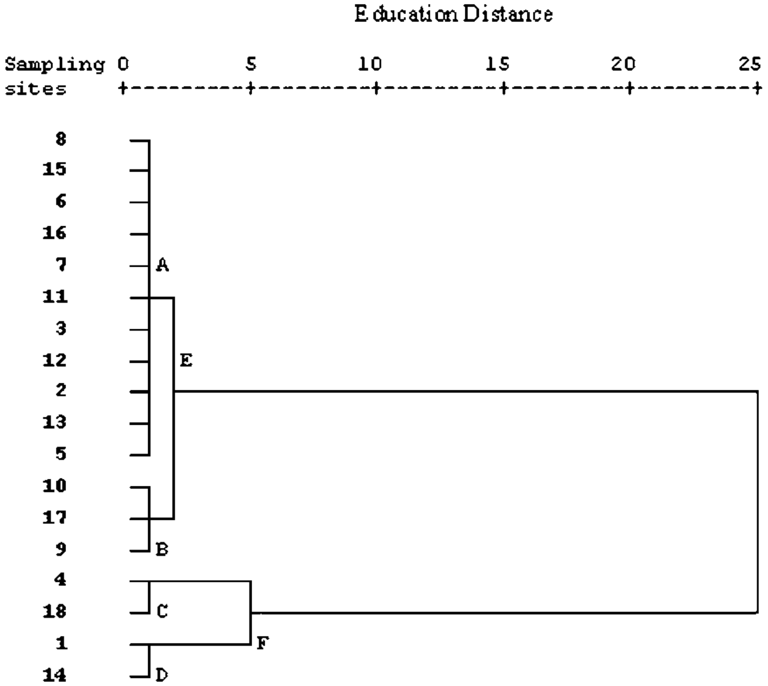

Figure 4. Dendrogram for hierarchical cluster analysis of 18 sampling locations based on nine heavy-metal concentrations in Suez Gulf sediments.

groups) in the hierachical cluster analysis, illustrates the importance of Ni, which influences the distribution of Pb, Cd, Cr, Zn, and Cu. Fe is associated with Mn, but otherwise Fe and Mn exert little affect on the elemental composition of the sediments. Similarly, Co does not seem to be a factor of any importance. Comparison between heavy-metal concentrations indicates that they are clustered at different distances, and the major differences are in the clusters of Cu and Co, which may be attributed to different sources of pollution by Cu and Co than other studied heavy metals. Figure 4 depicts a dendrogram derived by average linkage clustering of 18 sites based on all the nine heavy-metal concentrations in Suez Gulf sediments. Comparison between sampling sites indicates that at a distance about 1, four distinct clusters emerged: A (sampling sites 2, 3, 5, 6, 7, 8, 11, 12, 13, 15 and 16), B (sampling sites 9, 10 and 17), C (sampling sites 4 and 18) and D (sampling sites 1 and 14). At a greater distance (about 2), clusters A and B fuse, forming a single cluster E, while at distance about 5, clusters C and D were fused to form cluster F. The major differences are in the clustering of sampling sites in clusters E and F. The main reason for the considerable differences between sites in clusters E and F might be the different kinds of polluted substances arising from the different industrial and human activities along the Suez Gulf [3–5, 45].

4. Conclusion

This report describes the results of correlation, factor, and cluster analyses of elements in sediments collected from the Suez Gulf. The study has clearly shown that the Suez Gulf received heavy inputs of heavy metals from different sources of pollutions. The average concentrations of the nine heavy metals in the sediment studied were generally higher than the ERL but lower than the ERM values for most locations. Anthropogenic origin was the proposed major reason for pollution, with the exception of some local sites. These locations are far from the point of discharges from municipal, dock and industrial activities.

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