

ASSESSMENT OF HEAVY METALS AMONG SUSPENDED PARTICULATES AND DISSOLVED PHASES IN SUEZ CANAL WATER

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ABSTRACT: The concentrations and distribution of particulate and dissolved heavy metals, viz: Cu, Zn, Pb, Cd, Fe and Mn have been determined seasonally during 2003 in water samples collected from the Suez Canal. The presented data clarifies that the metals exhibited clear differences in their distribution between particulate and dissolved forms. The concentration of particulate heavy metals ranged between 0.09-3.13, 0.57-15.02, 0.18-3.87, 0.02-0.73, 2.74-49.62 and 0.15-5.08 $\mu\text{g/L}$ for Cu, Zn, Pb, Cd, Fe and Mn, respectively. In the same respect, these values for dissolved forms were 0.28-4.12, 0.57-9.08, 0.27-2.50, 0.02-1.24, 1.94-42.50 and 0.11-3.65 $\mu\text{g/L}$. The concentrations of particulate metals viz: Zn, Pb, Cd, Fe and Mn were high as compared to the dissolved forms. Dissolved copper, rather than particulate, showed the highest percentage of total copper. The particulate forms of Pb, Cd, Fe and Mn always had higher concentrations than the dissolved forms during the course of study except in the summer season. The northern part of the Suez Canal at Port Said showed mean concentrations of particulate and dissolved Cu = 1.43 and 2.10, Zn = 8.61 and 3.17, Pb = 1.72 and 1.23, Cd = 0.35 and 0.35, Fe = 23.49 and 15.83 and Mn = 2.09 and 1.82 $\mu\text{g/L}$. These high concentrations may be attributed to the greater activities, particularly loading and unloading operations at Port Said harbour, industrial effluents and domestic drainage of Port Said city. In contrast, the Sinai side could be considered as reference site, as it was almost clean, i.e., without harmful outfalls, where Cu = 0.16 and 0.56, Zn = 2.14 and 0.94, Pb = 6.29 and 3.44, Cd = 0.055 and 0.088, Fe = 6.29 and 3.44 and Mn = 0.56 and 0.26 $\mu\text{g/L}$ for particulate and dissolved metals respectively.

KEYWORDS: Speciation, heavy metals, suspended particulate, dissolved water, sediments, Suez Canal.

INTRODUCTION

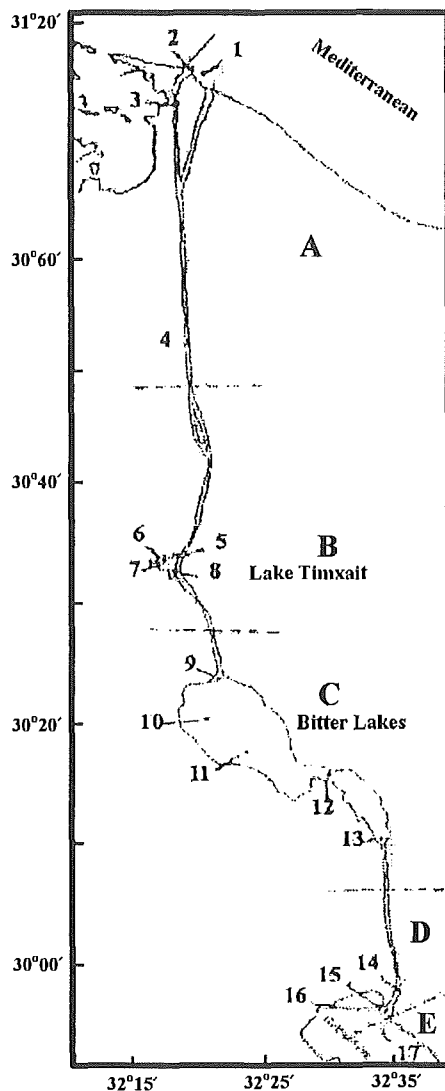
The Suez Canal is actually the only canal linking the Mediterranean Sea with the Red Sea. It is located between Suez and Port Said provinces (lying between longitudes 32°20' and 32°35'E and between latitudes 29°55' and 31°15'N with average length of 164 km along the major axis). Recent urbanization of the region has led to the situation that the Suez Canal system is suffering considerably from pollution, because it is a big navigation route. Oil pollution from leaks and bilges, domestic pressure, sewage pollution, pesticides and herbicides, agricultural run off, industrial effluent and thermal pollution from power plants are common types of pollution on the Suez Canal, which may directly or indirectly affect the marine life of the canal. Infrastructures established on the canal coasts are land-based sources of these type of pollution. All refuses coming from different sources are discharged directly or indirectly into the Suez Canal. These refuses contain large amount of chemical residues, especially metals and hydrocarbons (Hamed, 1996). In a natural

aquatic system, metals may be distributed among dissolved, colloidal or particulate fractions as the results of reactions such as precipitation and coprecipitation or complexation with organic or inorganic ligands. In some cases, distributions may depend on the presence of more than one oxidation state for the metal (Leckie and James, 1976). The aim of this work is to assess the distribution of heavy metals among suspended particulates and dissolved phases in the Suez Canal water.

MATERIALS AND METHODS

Sampling:

Using Nansen bottles, surface (0-0.5 m depth) water samples were collected seasonally during February, May, August and November 2003 from seventeen stations divided into four sectors (A, B, C and D) between Suez and Port Said provinces (Fig. 1). One more station was located in the southern part of the canal at the Sinai side (sector E).



Sector A (Port Said):

- 1- Port Fouad,
- 2- Port Said,
- 3- El-Raswa and
- 4- El-Qantara.

Sector B (Timsah Lake):

- 5- Northern entrance of the Lake,
- 6- in front of Ismailia channel,
- 7- in front of western lagoon and 8- southern entrance of the lake.

Sector C (Bitter Lakes):

- 9- El-Defresoir,
- 10- Fayed,
- 11- Fanara,
- 12- Kabreit and
- 13- Shandora.

Sector D (Suez Bay):

- 14- In front of El-Dersa pond,
- 15- Southern entrance of the canal 16- El-Zeityia (Suez Bay).

Sector E (Sinai side):

- 17- Ain Moussa.

Procedures:

After collecting the samples and filtering them through 0.45 μm fiberglass paper (APHA, 1989); each filtered mass was kept for analysis while the filtrate was treated with ammonium pyrrolidine dithiocarbamate (APDC) to complex the heavy metals. After shaking well, methyl isobutyl ketone (MIBK) was used for extraction (Brooks *et al.*, 1967). The particulate for each sample was dissolved in 3 mL of concentrated HNO_3 plus H_2O_2 (Tesier *et al.*, 1973) and treated as the filtrate. Measurements of the heavy solution for the heavy metals were carried out using Perkin-Elmer 2380 atomic absorption spectrometer.

RESULTS AND DISCUSSION**Regional distribution of heavy metals:**

The Suez Canal receives various land-based sources of wastes discharged from tankers passing across the canal, domestic wastes, industrial effluents, and fish processing wastes. Moreover, Port Said represents the most industrialized area in the canal at the inlet of the Mediterranean and shows high levels of heavy metals, whereas minimum levels were recorded at Sinai site (Tables 1-6). In the southern part (sector D), Suez showed mean concentrations of particulate and dissolved metals for Cu (0.94 and 1.48), Zn (7.31 and 2.89), Pb (1.49 and 1.21), Cd (0.25 and 0.30), Fe (19.10 and 7.41) and Mn (1.38 and 1.37) $\mu\text{g/L}$, respectively. This part is affected by the invading water coming from Suez Bay where there are many sources of pollution such as domestic drainage from Suez city, industrial wastes of the fertilizer company, power stations and oil refineries. The middle part (sectors B and C), near Ismailia, shows slightly higher concentration of Cu (0.68 and 0.91), Zn (3.57 and 3.28), Pb (1.05 and 0.77), Cd (0.21 and 0.18), Fe (11.11 and 9.2) and Mn (1.11 and 0.96) $\mu\text{g/L}$, respectively. This is probably the result of agricultural effluents, shipyards of the Suez Canal and sewage discharge. The northern part of the Suez Canal at Port Said (sector A) has mean concentrations of Cu (1.43 and 2.10), Zn (8.61 and 3.17), Pb (1.72 and 1.23), Cd (0.35 and 0.35), Fe (23.49 and 15.83) and Mn (2.09 and 1.82) $\mu\text{g/L}$, respectively; because this area possesses high sources of activities, such as loading and unloading operations at Port Said harbor and particularly the industrial effluents and domestic drainage of Port Said city. The Sinai side (sector E) might be used as control, as it is almost clean and without harmful outfalls, where the concentrations of Cu = 0.16 and 0.56, Zn = 2.14 and 0.94, Pb = 6.29 and 3.44, Cd = 0.055 and 0.088, Fe = 6.29 and 3.44 and Mn = 0.56 and 0.26 $\mu\text{g/L}$ for particulate and dissolved metals, respectively have been recorded.

Seasonal distribution of heavy metals:**Copper (Table 1):**

The annual total Cu ranged from 0.722 $\mu\text{g/L}$ at station 17 to 4.41 $\mu\text{g/L}$ at station 2, with the annual particulate Cu measured from 0.16 $\mu\text{g/L}$ at station 17 to 2.04 at station 2, and the annual dissolved Cu from 0.56 $\mu\text{g/L}$ at station 17 to 2.57 $\mu\text{g/L}$ at station 3. The regional variation of copper reached its maximum values (2.77, 1.15 and 1.61 $\mu\text{g/L}$) during the spring for total, particulates and dissolved copper, respectively. Their corresponding minimum values (1.62, 0.69 and 0.93 $\mu\text{g/L}$) were recorded during the summer. Spring had the maximum average values of total, particulate and dissolved

copper followed by winter, whereas autumn and summer attained the minimum values. Dissolved, rather than the particulate copper, reached the highest level of total copper (Table 7). In seawater, no more than 10% of total Cu may be bound to humic acids (Mantoura *et al.*, 1978). Moore (1991) showed that desorption of copper from sediments was enhanced by increasing salinity and the concomitant competition for binding sites with chloride ions.

Table 1. Seasonal variation of copper ($\mu\text{g/L}$) in different types of surface seawater of the Suez Canal during 2003.

Seasons	Winter			Spring			Summer			Autumn			Annual mean \pm SD		
	T	P	D	T	P	D	T	P	D	T	P	D	T	P	D
1	3.65	1.29	2.36	4.72	1.89	2.83	2.72	1.03	1.69	3.17	1.22	1.95	3.56 \pm 0.74	1.36 \pm 0.32	2.21 \pm 0.43
2	3.89	2.25	1.64	7.25	3.13	4.12	2.13	0.90	1.24	4.38	1.87	2.51	4.41 \pm 1.84	2.04 \pm 0.80	2.38 \pm 1.11
3	4.72	1.66	3.06	5.40	1.64	3.76	3.05	1.36	1.69	2.57	0.80	1.77	3.94 \pm 1.16	1.37 \pm 0.35	2.57 \pm 0.88
4	2.01	0.81	1.20	2.57	1.43	1.14	1.68	0.64	1.04	2.46	0.92	1.54	2.18 \pm 0.36	0.95 \pm 0.29	1.23 \pm 0.19
Sector A													3.52 \pm 0.83	1.43 \pm 0.39	2.10 \pm 0.52
5	1.51	0.54	0.97	2.36	1.21	1.05	1.25	0.85	0.40	0.87	0.59	0.28	1.5 \pm 0.83	0.80 \pm 0.27	0.67 \pm 0.34
6	2.14	0.60	1.54	2.79	1.37	1.42	1.63	0.76	0.87	1.36	0.70	0.66	1.98 \pm 0.55	0.86 \pm 0.30	1.12 \pm 0.37
7	3.42	0.49	2.93	2.45	0.80	1.65	1.80	0.68	1.12	0.00	0.96	1.25	2.47 \pm 0.60	0.73 \pm 0.17	1.74 \pm 0.72
8	1.16	0.72	0.44	1.78	1.13	0.65	0.91	0.44	0.47	1.45	0.51	0.94	1.33 \pm 0.33	0.70 \pm 0.27	0.63 \pm 0.20
Sector B													1.82 \pm 0.45	0.77 \pm 0.06	1.04 \pm 0.41
9	1.30	0.52	0.78	0.87	0.31	0.56	0.86	0.54	0.32	1.23	0.49	0.74	1.07 \pm 0.20	0.47 \pm 0.09	0.60 \pm 0.18
10	1.53	1.20	0.33	1.91	0.69	1.22	1.28	0.57	0.71	1.05	0.47	0.58	1.44 \pm 0.32	0.73 \pm 0.28	0.71 \pm 0.30
11	1.39	0.48	0.91	1.56	0.87	0.69	1.06	0.60	0.46	1.17	0.39	0.78	1.29 \pm 0.19	0.59 \pm 0.18	0.71 \pm 0.10
12	2.32	0.50	1.82	2.12	0.94	1.18	1.69	0.89	0.80	1.42	0.52	0.90	1.89 \pm 0.35	0.71 \pm 0.20	1.17 \pm 0.40
13	1.65	0.57	1.08	1.27	0.71	0.56	1.12	0.35	0.77	0.89	0.40	0.49	1.23 \pm 0.28	0.51 \pm 0.14	0.73 \pm 0.23
Sector C													1.38 \pm 0.28	0.60 \pm 0.10	0.78 \pm 0.20
14	2.86	1.32	1.54	3.21	1.13	2.08	2.48	0.95	1.53	2.79	1.31	1.48	2.85 \pm 0.28	1.18 \pm 0.15	1.66 \pm 0.20
15	2.54	1.20	1.34	3.79	1.35	2.44	1.71	0.59	1.12	2.33	1.08	1.25	2.59 \pm 0.76	1.06 \pm 0.29	1.54 \pm 0.50
16	1.92	0.60	1.32	2.24	0.77	1.47	1.54	0.52	1.02	1.68	0.48	1.20	1.85 \pm 0.27	0.59 \pm 0.11	1.25 \pm 0.10
Sector D													2.43 \pm 0.42	0.94 \pm 0.25	1.48 \pm 0.13
Sector E 17	0.96	0.29	0.67	0.76	0.15	0.61	0.69	0.11	0.58	0.48	0.09	0.39	0.72 \pm 0.17	0.16 \pm 0.08	0.56 \pm 0.10
Mean \pm SD	2.29 \pm 1.08	0.88 \pm 0.52	1.41 \pm 0.78	2.77 \pm 1.70	1.15 \pm 0.68	1.61 \pm 1.10	1.62 \pm 0.66	0.69 \pm 0.29	0.93 \pm 0.43	1.85 \pm 1.00	0.75 \pm 0.43	1.08 \pm 0.60	2.13 \pm 0.44	0.87 \pm 0.18	1.26 \pm 0.27

T= Total, P=Particulate and D= Dissolved

Table 2. Seasonal variation of zinc ($\mu\text{g/L}$) in different types of surface seawater of the Suez Canal during 2003.

Seasons	Winter			Spring			Summer			Autumn			Annual mean \pm SD		
Stations	T	P	D	T	P	D	T	P	D	T	P	D	T	P	D
1	10.82	7.25	3.57	14.52	9.75	4.77	8.84	7.28	1.56	5.74	3.85	1.89	9.98 \pm 3.68	7.03 \pm 2.42	2.95 \pm 1.50
2	14.45	9.88	4.57	19.86	12.60	7.26	11.67	9.05	2.62	9.80	7.64	2.16	13.95 \pm 4.38	9.79 \pm 2.09	4.15 \pm 2.32
3	17.33	13.02	4.31	23.10	15.02	9.08	12.45	8.14	4.31	11.63	6.21	5.42	16.13 \pm 2.32	10.60 \pm 4.11	3.07 \pm 1.70
4	11.29	9.11	2.18	12.90	8.16	4.74	7.72	6.22	1.50	6.28	4.57	1.71	9.55 \pm 3.07	7.02 \pm 2.03	2.53 \pm 1.50
Sector A													12.40 \pm 3.18	8.61 \pm 1.86	3.17 \pm 0.69
5	7.84	4.99	2.85	5.80	3.66	2.14	4.49	2.78	1.71	4.60	3.01	1.59	5.68 \pm 1.56	3.61 \pm 0.99	2.07 \pm 0.57
6	9.68	8.36	1.32	6.73	4.21	2.52	7.40	4.52	2.88	3.33	2.30	1.03	6.79 \pm 2.63	4.85 \pm 2.54	1.94 \pm 0.90
7	10.44	7.53	2.91	8.36	5.06	3.30	5.83	3.29	2.54	4.78	2.71	2.07	7.35 \pm 2.55	4.65 \pm 2.17	2.71 \pm 0.53
8	6.79	5.48	1.31	4.45	3.21	1.24	3.97	2.45	1.52	2.85	1.96	0.89	4.52 \pm 1.66	3.28 \pm 1.56	1.24 \pm 0.26
Sector B													6.09 \pm 1.25	4.10 \pm 0.77	1.99 \pm 0.60
9	5.58	4.85	0.73	6.40	3.82	2.58	2.31	1.62	0.69	2.63	1.79	0.84	4.23 \pm 2.06	3.02 \pm 1.58	1.21 \pm 0.92
10	6.38	5.12	1.26	4.47	3.65	0.82	3.46	2.38	1.08	2.98	2.26	0.72	4.32 \pm 1.51	3.35 \pm 1.34	0.97 \pm 0.25
11	5.23	3.98	1.25	6.14	4.58	1.56	4.21	2.99	1.22	3.75	2.45	1.30	4.83 \pm 1.07	3.50 \pm 0.96	1.33 \pm 0.16
12	5.69	4.30	1.39	5.02	3.14	1.88	2.85	1.46	1.39	2.12	1.43	0.69	3.92 \pm 1.71	2.58 \pm 1.40	1.34 \pm 0.49
13	6.14	3.95	2.19	4.68	2.89	1.79	3.62	2.33	1.29	2.74	1.55	1.19	4.30 \pm 1.46	2.68 \pm 1.01	1.62 \pm 0.46
Sector C													4.32 \pm 0.33	3.03 \pm 0.40	1.29 \pm 0.24
14	8.60	6.90	1.70	15.01	12.23	2.78	10.62	6.87	3.75	4.89	3.41	1.48	9.78 \pm 4.22	7.35 \pm 3.64	2.43 \pm 1.05
15	13.37	9.20	4.17	16.98	11.74	5.24	8.04	5.61	2.43	7.46	4.64	2.82	11.46 \pm 4.54	7.80 \pm 3.28	3.67 \pm 1.29
16	9.12	6.86	2.26	13.26	8.99	4.27	9.12	7.46	1.66	5.88	3.78	2.10	9.35 \pm 3.02	6.77 \pm 2.19	2.57 \pm 1.16
Sector D													10.20 \pm 1.12	7.31 \pm 0.52	2.89 \pm 0.68
Sector E 17	4.32	3.06	1.26	3.95	2.61	1.34	2.16	1.59	0.57	1.89	1.31	0.58	3.08 \pm 1.23	2.14 \pm 0.83	0.94 \pm 0.42
Mean \pm SD	9.00 \pm 3.62	6.70 \pm 2.62	2.31 \pm 1.22	10.10 \pm 6.08	6.78 \pm 4.13	3.37 \pm 2.27	6.40 \pm 3.35	4.47 \pm 2.58	1.92 \pm 1.03	4.90 \pm 2.71	3.23 \pm 1.75	1.68 \pm 1.15	7.22 \pm 3.95	5.04 \pm 2.79	2.06 \pm 0.97

Zinc (Table 2):

The annual total Zinc ranged from 3.08 $\mu\text{g/L}$ at station 17 to 16.13 $\mu\text{g/L}$ at station 3, with the annual particulate Zn varying from 2.14 $\mu\text{g/L}$ at station 17 to 10.60 $\mu\text{g/L}$ at station 3, while the annual dissolved Zn varied from 0.94 $\mu\text{g/L}$ at station 17 to 4.15 $\mu\text{g/L}$ at station 2. Regional variation of zinc was maximum (10.10, 6.78 and 3.37 $\mu\text{g/L}$) during spring for total, particulate and dissolved zinc, respectively. Their respective minimum values of 4.90, 3.23 and 1.68 $\mu\text{g/L}$ were recorded during autumn. Spring exhibited the maximum mean levels for all three forms of zinc and particulate zinc was the dominant form for all seasons comprising about 65.92% to 74.41% of the total zinc (Table 7). The higher zinc input during spring that bound readily with many organic ligands, particularly in presence of nitrogen or sulfur donor atoms, might explain the higher level particulate zinc over dissolved zinc. Moore (1991) indicated that the binding of zinc to suspended particulates depended on pH and E_h conditions, and the input of anthropogenically derived zinc.

Lead (Table 3):

The annual total Pb ranged from 0.85 $\mu\text{g/L}$ at station 17 to 3.61 $\mu\text{g/L}$ at station 3, with the annual particulate Pb varying from 0.31 $\mu\text{g/L}$ at station 17 to 2.12 $\mu\text{g/L}$ at station 15, while the annual dissolved Pb was from 0.54 $\mu\text{g/L}$ at station 17 to 1.52 $\mu\text{g/L}$ at station 2. The regional variation of Pb reached its maximum values (2.77, 1.83 and 0.95 $\mu\text{g/L}$) during spring for total, particulates and dissolved Pb, respectively. Their minimum values were 1.91 $\mu\text{g/L}$ for total Pb during autumn, 0.64 $\mu\text{g/L}$ for particulate Pb during summer and 0.684 $\mu\text{g/L}$ for dissolved Pb during winter. The relative decrease in Pb concentration in winter may be attributed to the relative decrease in the decomposition rate of organic matter with lower temperatures (Aboul-Nagah, 1979 and Hafez, 1982). Table (7) shows that particulate Pb was dominant at all seasons except during summer, where dissolved Pb constituted a major portion (68.97%) of total lead. Summer was characterized by high salinities accompanied by high chloride ions (Morcos and Riley, 1966), where lead typically desorbed from sediments and suspended solids in estuaries owing to competition with chlorides, thus producing appreciable increases in soluble lead in the water column (Ferrari and Ferrario, 1989).

Cadmium (Table 4):

The annual total Cd ranged from 0.143 $\mu\text{g/L}$ at station 17 to 0.83 $\mu\text{g/L}$ at station 2, with the annual particulate Cd varying from 0.055 $\mu\text{g/L}$ at station 17 to 0.44 $\mu\text{g/L}$ at station 2, while the annual dissolved Cd was measured from 0.088 $\mu\text{g/L}$ at station 17 to 0.40 $\mu\text{g/L}$ at station 15. The regional variation of Cd reached its maximum values (0.92 and 0.604 $\mu\text{g/L}$) during summer for total and dissolved and 0.376 $\mu\text{g/L}$ for particulate Cd during autumn, while their minimum values of 0.194, 0.12 and 0.076 $\mu\text{g/L}$ were reported during winter for total, particulate and dissolved Cd, respectively. Therefore, particulate Cd was the dominant form for all seasons but only during the summer season what? and the dissolved Cd constituted a major percentage (65.65%) of total Cd. As salinities increased during the summer, Cd concentrations increased also. Zirino and Yamamoto (1972) and Abdelmoneim and Fattouh (1994) indicated that at higher salinities, Cd interacted primarily with chloride ions, while the reverse happened for particulate Cd.

Table 3. Seasonal variation of lead ($\mu\text{g/L}$) in different types of surface seawater of the Suez Canal during 2003.

Seasons	Winter			Spring			Summer			Autumn			Annual mean \pm SD		
Stations	T	P	D	T	P	D	T	P	D	T	P	D	T	P	D
1	2.46	1.68	0.78	3.37	2.56	0.81	2.28	0.53	1.75	2.16	1.28	0.88	2.57 \pm 0.55	1.51 \pm 0.85	1.06 \pm 0.47
2	3.41	1.89	1.52	4.15	3.12	1.03	3.96	1.62	2.34	2.93	1.76	1.17	3.61 \pm 0.55	2.10 \pm 0.69	1.52 \pm 0.59
3	2.79	2.04	0.75	5.21	3.87	1.34	3.14	0.64	2.50	2.79	1.86	0.93	3.48 \pm 1.16	2.10 \pm 1.33	1.38 \pm 0.77
4	1.88	0.98	0.9	2.74	1.91	0.83	2.44	0.81	1.63	1.31	0.90	0.41	2.09 \pm 0.63	1.15 \pm 0.51	0.94 \pm 0.51
Sector A													2.94 \pm 0.73	1.72 \pm 0.47	1.23 \pm 0.27
5	1.45	0.75	0.70	2.33	1.56	0.77	0.88	0.31	0.57	1.77	1.48	0.29	1.61 \pm 0.61	1.03 \pm 0.60	0.58 \pm 0.22
6	1.69	1.02	0.67	2.85	1.63	1.22	1.54	0.32	1.22	1.14	0.73	0.41	1.81 \pm 0.73	0.93 \pm 0.55	0.88 \pm 0.41
7	2.32	1.45	0.87	3.12	1.87	1.25	2.28	0.72	1.56	2.60	1.18	1.42	2.58 \pm 0.39	1.31 \pm 0.48	1.28 \pm 0.30
8	1.73	0.93	0.80	1.96	1.46	0.50	1.07	0.24	0.83	1.92	1.40	0.52	1.67 \pm 0.41	1.01 \pm 0.56	0.66 \pm 0.181
Sector B													1.92 \pm 0.45	1.07 \pm 0.17	0.85 \pm 0.31
9	1.81	1.30	0.51	2.18	1.65	0.53	1.75	0.60	1.15	1.48	0.79	0.69	1.81 \pm 0.29	1.09 \pm 0.48	0.72 \pm 0.30
10	2.28	1.81	0.47	2.70	1.46	1.24	1.52	0.74	0.78	1.99	1.35	0.64	2.12 \pm 0.50	1.34 \pm 0.45	0.78 \pm 0.33
11	1.54	0.87	0.67	1.81	1.15	0.66	1.26	0.46	0.80	0.97	0.7	0.27	1.40 \pm 0.36	0.80 \pm 0.29	0.60 \pm 0.23
12	1.97	1.55	0.42	1.16	0.69	0.47	2.04	0.68	1.36	1.66	1.04	0.62	1.71 \pm 0.40	0.99 \pm 0.41	0.72 \pm 0.44
13	1.04	0.73	0.31	1.89	1.10	0.79	1.63	0.55	1.08	1.74	1.36	0.38	1.58 \pm 0.37	0.94 \pm 0.36	0.64 \pm 0.36
Sector C													1.72 \pm 0.27	1.03 \pm 0.20	0.69 \pm 0.07
14	2.12	1.38	0.74	3.50	2.08	1.42	3.02	0.77	2.25	2.29	1.26	1.03	2.73 \pm 0.64	1.37 \pm 0.54	1.36 \pm 0.66
15	2.56	2.12	0.44	4.86	3.16	1.70	2.76	0.97	1.79	3.67	2.24	1.43	3.46 \pm 1.05	2.12 \pm 0.09	1.34 \pm 0.62
16	1.68	1.29	0.39	2.48	1.32	1.16	1.98	0.50	1.48	1.46	0.81	0.65	1.90 \pm 0.44	0.98 \pm 0.40	0.92 \pm 0.49
Sector D													2.70 \pm 0.78	1.49 \pm 0.58	1.21 \pm 0.25
Sector E 17	0.91	0.23	0.68	0.85	0.48	0.37	1.02	0.36	0.66	0.63	0.18	0.45	0.85 \pm 0.16	0.31 \pm 0.14	0.54 \pm 0.15
Mean \pm SD	1.98 \pm 0.63	1.29 \pm 0.52	0.68 \pm 0.28	2.77 \pm 1.19	1.83 \pm 0.90	0.95 \pm 0.38	2.03 \pm 0.84	0.64 \pm 0.32	1.40 \pm 0.60	1.91 \pm 0.77	1.19 \pm 0.50	0.72 \pm 0.37	2.03 \pm 0.83	1.12 \pm 0.54	0.90 \pm 0.31

Table 4. Seasonal variation of cadmium ($\mu\text{g/L}$) in different types of surface seawater of the Suez Canal during 2003.

Seasons	Winter			Spring			Summer			Autumn			Annual mean \pm SD		
Stations	T	P	D	T	P	D	T	P	D	T	P	D	T	P	D
1	0.17	0.15	0.02	0.21	0.15	0.06	1.54	0.30	1.24	0.67	0.45	0.22	0.65 \pm 0.64	0.26 \pm 0.14	0.39 \pm 0.58
2	0.31	0.19	0.12	0.43	0.36	0.07	1.78	0.58	1.20	0.79	0.62	0.17	0.83 \pm 0.67	0.44 \pm 0.20	0.39 \pm 0.54
3	0.45	0.32	0.13	0.36	0.25	0.11	1.31	0.34	0.97	0.84	0.59	0.25	0.74 \pm 0.43	0.38 \pm 0.15	0.37 \pm 0.41
4	0.19	0.14	0.05	0.30	0.18	0.12	0.98	0.46	0.52	0.71	0.48	0.23	0.55 \pm 0.37	0.32 \pm 0.18	0.23 \pm 0.21
Sector A													0.69 \pm 0.12	0.35 \pm 0.08	0.35 \pm 0.08
5	0.13	0.09	0.04	0.10	0.07	0.03	0.89	0.38	0.51	0.54	0.36	0.18	0.42 \pm 0.37	0.23 \pm 0.17	0.19 \pm 0.22
6	0.11	0.05	0.06	0.11	0.05	0.06	0.56	0.16	0.40	0.47	0.28	0.19	0.31 \pm 0.24	0.14 \pm 0.11	0.18 \pm 0.16
7	0.25	0.17	0.08	0.31	0.22	0.09	1.26	0.47	0.79	0.66	0.40	0.26	0.62 \pm 0.46	0.32 \pm 0.14	0.31 \pm 0.33
8	0.18	0.11	0.07	0.27	0.18	0.09	0.92	0.73	0.17	0.50	0.31	0.19	0.47 \pm 0.33	0.33 \pm 0.28	0.13 \pm 0.06
Sector B													0.46 \pm 0.13	0.26 \pm 0.09	0.20 \pm 0.08
9	0.12	0.02	0.10	0.19	0.12	0.07	0.75	0.13	0.62	0.38	0.29	0.09	0.36 \pm 0.28	0.14 \pm 0.11	0.22 \pm 0.27
10	0.15	0.08	0.07	0.09	0.04	0.05	0.67	0.23	0.44	0.36	0.21	0.15	0.32 \pm 0.26	0.14 \pm 0.09	0.18 \pm 0.18
11	0.10	0.06	0.04	0.07	0.03	0.04	0.48	0.18	0.30	0.59	0.33	0.26	0.31 \pm 0.26	0.15 \pm 0.14	0.16 \pm 0.14
12	0.26	0.16	0.10	0.20	0.11	0.09	0.39	0.14	0.25	0.61	0.50	0.11	0.37 \pm 0.18	0.23 \pm 0.18	0.14 \pm 0.08
13	0.09	0.04	0.05	0.26	0.12	0.14	0.50	0.12	0.38	0.32	0.23	0.09	0.29 \pm 0.17	0.13 \pm 0.08	0.17 \pm 0.15
Sector C													0.33 \pm 0.03	0.16 \pm 0.04	0.17 \pm 0.03
14	0.23	0.15	0.08	0.17	0.09	0.08	1.08	0.22	0.86	0.72	0.56	0.16	0.55 \pm 0.43	0.26 \pm 0.21	0.30 \pm 0.38
15	0.29	0.16	0.13	0.25	0.13	0.12	1.47	0.45	1.02	0.75	0.42	0.33	0.69 \pm 0.57	0.29 \pm 0.17	0.40 \pm 0.42
16	0.19	0.10	0.09	0.14	0.06	0.08	0.80	0.33	0.47	0.43	0.30	0.13	0.39 \pm 0.30	0.20 \pm 0.14	0.19 \pm 0.19
Sector D													0.54 \pm 0.15	0.25 \pm 0.05	0.30 \pm 0.11
Sector E 17	0.08	0.02	0.06	0.07	0.03	0.04	0.24	0.11	0.13	0.18	0.06	0.12	0.14 \pm 0.08	0.06 \pm 0.4	0.09 \pm 0.04
Mean \pm SD	0.19 \pm 0.10	0.12 \pm 0.08	0.076 \pm 0.032	0.21 \pm 0.11	0.13 \pm 0.09	0.08 \pm 0.03	0.92 \pm 0.44	0.31 \pm 0.18	0.6 \pm 0.35	0.56 \pm 0.18	0.38 \pm 0.15	0.18 \pm 0.07	0.43 \pm 0.21	0.21 \pm 0.10	0.22 \pm 0.10

Iron (Table 5):

Annually, the concentration of total iron ranged from 8.98 µg/L at station 17 to 51.0 µg/L at station 3 and the particulate iron ranged from 6.29 µg/L at station 17 to 30.15 µg/L at station 2. The dissolved iron ranged from 3.12 µg/L at station 15 to 21.66 µg/L at station 3. According to the regional sense, the maximum Fe concentrations of 30.84 and 19.68 µg/L were recorded during summer for total and dissolved Fe, respectively and 19.63 during winter for particulate Fe. Their minimum values of 17.33 and 5.22 µg/L were recorded during autumn for total and dissolved Fe, respectively and 11.40 µg/L during summer for particulate Fe. Table (7) shows that the particulate forms had higher concentrations than the dissolved forms during the course of study except for the summer season. Only during summer, the dissolved form of Fe constituted a major percentage (63.81%) of total Fe. This may be explained by the fact that during the summer, oxygen concentrations in the water-sediment interface decreased to almost zero. This led to reduction of Fe³⁺ to soluble Fe²⁺, which was then transported upwards in the water column (Moore, 1991).

Manganese (Table 6):

Annually, the concentration of total Mn ranged from 0.82 µg/L at station 17 to 4.88 µg/L at station 3. Particulate Mn ranged from 0.56 µg/L at stations 10 and 17 to 2.73 µg/L at station 3. Dissolved Mn ranged from 0.26 µg/L at station 17 to 2.16 µg/L at station 3. According to the regional sense, the total and particulate Mn reached their maximum values (2.78 and 1.92 µg/L) during the winter, while the dissolved form showed maximum values (1.67 µg/L) during summer and autumn. The minimum values of 1.96 and 0.59 µg/L were recorded during spring for total and dissolved Mn, respectively and 0.82 µg/L during summer for particulate Mn. During summer and autumn, dissolved Mn reached high rates of 67.07 and 60.51% for the total Mn, respectively (Table 7). In summer, the depletion of oxygen at the water-sediment interface caused the reduction of Mn⁴⁺ to soluble Mn²⁺, which was then transported upward in the water column. Oxidation of Mn occurs much slowly than the oxidation of Fe. As a result, soluble Mn in water is often supplied almost entirely from in situ reductions in the water column, whereas soluble Fe is supplied by reduction in the sediment (Moore, 1991).

Statistical analysis:

The presented data show that the metals exhibited clear differences in their distributions between particulate and dissolved forms. Most particulate metals exhibited higher concentration range than that of the dissolved metals. However, both particulate and dissolved forms showed high significant correlations with each other and with total metals (Table 8). This may indicate that the distribution of metals in different phases is governed by interactions of several variables: these include the suspended matter loads of the effluents, their outflow rate concentrations and physical forms of the metals in the effluent, stratification and stability of seawater and the current velocities and patterns (Aboul-Dahab, 1985). Statistical analysis indicated that zinc was highly correlated with manganese and copper, giving high significant positive correlations ($r = 0.94, 0.92$ and $0.89, 0.91$) for dissolved and particulate metals, respectively. This might be due to adsorption of zinc by hydrous iron oxide (El-Sayed and El-Sayed, 1980). However, the obtained correlation ($r = 0.87$ and 0.92) between zinc and copper was due to insolubility

of both metals in the oxidized state and formation of sulfides in reducing conditions (Schindler, 1967). The positive correlation between copper and manganese ($r = 0.91$ and 0.96) indicated that copper was mostly adsorbed by amorphous manganese oxyhydroxide particles (Johnson, 1986).

Table 5. Seasonal variation of iron ($\mu\text{g/L}$) in different types of surface seawater of the Suez Canal during 2003.

Seasons	Winter			Spring			Summer			Autumn			Annual mean \pm SD		
Stations	T	P	D	T	P	D	T	P	D	T	P	D	T	P	D
1	30.21	22.90	7.31	42.50	23.70	18.80	37.80	17.59	20.21	18.25	16.05	2.20	32.19 \pm 10.85	20.06 \pm 3.81	12.13 \pm 8.79
2	48.56	31.87	16.69	63.24	49.62	13.42	45.07	11.39	33.68	32.46	27.70	4.76	47.33 \pm 12.66	30.15 \pm 15.71	17.14 \pm 12.12
3	51.74	40.62	11.12	57.31	40.43	16.88	58.27	15.77	42.50	36.68	20.56	16.12	51.00 \pm 9.97	29.35 \pm 13.06	21.66 \pm 3.00
4	26.30	16.11	10.19	28.77	18.92	9.85	29.92	7.80	22.12	21.85	14.42	7.43	26.71 \pm 3.57	14.31 \pm 4.72	12.40 \pm 6.60
Sector A													39.31 \pm 11.70	23.49 \pm 7.62	15.83 \pm 4.52
5	24.75	15.70	9.05	26.30	14.30	12.00	31.56	13.19	18.37	15.90	8.51	7.39	24.63 \pm 6.51	12.93 \pm 3.12	11.70 \pm 4.84
6	37.24	26.16	11.08	33.07	27.51	5.56	35.44	10.40	25.04	16.32	10.85	5.47	30.52 \pm 9.62	10.73 \pm 9.38	11.79 \pm 9.22
7	28.85	24.48	4.37	25.52	3.72	21.8	28.30	11.55	16.75	19.77	15.48	4.29	25.61 \pm 4.16	13.81 \pm 8.63	11.80 \pm 8.78
8	20.62	17.33	3.29	22.45	13.16	9.29	23.83	11.53	12.30	7.14	6.22	0.92	18.51 \pm 7.69	12.06 \pm 4.60	6.45 \pm 5.26
Sector B													24.82 \pm 4.93	12.38 \pm 1.31	10.44 \pm 2.66
9	17.33	12.67	4.66	15.88	8.36	7.52	22.75	7.27	15.48	11.22	8.90	2.32	16.80 \pm 4.75	9.30 \pm 2.35	7.50 \pm 5.73
10	21.42	13.24	8.18	26.51	11.47	15.06	28.17	10.66	17.51	21.07	12.19	8.88	24.29 \pm 3.59	11.96 \pm 1.07	12.41 \pm 4.60
11	18.78	10.30	8.48	11.20	8.75	2.45	27.36	12.57	14.79	9.17	2.74	6.43	16.63 \pm 8.24	8.59 \pm 4.20	8.04 \pm 5.15
12	15.51	9.26	6.25	19.27	12.83	6.44	20.66	9.80	11.86	15.98	11.83	4.15	17.86 \pm 2.51	10.93 \pm 1.68	7.17 \pm 3.29
13	11.60	7.54	4.06	14.64	10.41	4.23	19.14	10.19	8.95	6.81	5.27	1.54	13.05 \pm 5.18	8.35 \pm 2.43	4.70 \pm 3.05
Sector C													17.73 \pm 4.09	9.83 \pm 1.56	7.69 \pm 2.80
14	35.16	28.12	7.04	37.05	34.23	2.82	33.42	9.78	23.64	16.58	9.25	7.33	30.55 \pm 9.43	20.35 \pm 12.75	10.21 \pm 9.19
15	44.22	30.15	14.07	28.15	22.19	5.96	40.5	13.25	27.25	22.30	17.09	5.21	33.79 \pm 10.29	20.67 \pm 7.30	3.12 \pm 10.24
16	29.47	20.97	8.50	24.96	17.44	7.52	29.24	12.04	17.20	17.02	14.65	2.37	25.17 \pm 5.82	16.27 \pm 3.83	8.90 \pm 6.15
Sector D													29.84 \pm 4.35	19.10 \pm 2.45	7.41 \pm 3.77
Sector E 17	9.12	6.32	2.80	7.91	5.77	2.14	12.84	8.96	6.88	6.06	4.12	1.94	8.98 \pm 2.86	6.29 \pm 2.01	3.44 \pm 2.32
Mean \pm SD	27.70 \pm 12.46	19.63 \pm 9.66	8.07 \pm 3.80	28.51 \pm 14.90	18.99 \pm 12.72	9.51 \pm 5.95	30.84 \pm 10.70	11.40 \pm 2.62	19.68 \pm 8.95	17.33 \pm 8.39	12.11 \pm 6.35	5.22 \pm 3.70	26.10 \pm 5.99	15.53 \pm 4.38	10.62 \pm 6.32

Table 6. Seasonal variation of manganese ($\mu\text{g/L}$) in different types of surface seawater of the Suez Canal during 2003.

Seasons	Winter			Spring			Summer			Autumn			Annual mean \pm SD		
Stations	T	P	D	T	P	D	T	P	D	T	P	D	T	P	D
1	3.75	2.44	1.31	2.86	1.89	0.97	3.65	1.34	2.31	2.26	0.46	1.8	3.13 \pm 0.70	1.53 \pm 0.84	1.60 \pm 0.58
2	5.17	3.65	1.52	4.63	3.24	1.39	4.12	1.04	3.08	3.87	1.34	2.53	4.45 \pm 0.58	2.32 \pm 1.32	2.13 \pm 1.80
3	6.24	5.08	1.16	3.21	2.75	0.46	4.76	1.41	3.35	5.32	1.67	3.65	4.88 \pm 1.27	2.73 \pm 1.67	2.16 \pm 1.58
4	3.93	2.30	1.63	2.04	1.48	0.56	2.47	0.59	1.88	4.25	2.77	1.48	3.17 \pm 1.08	1.79 \pm 0.96	1.39 \pm 0.58
Sector A													3.91 \pm 0.89	2.09 \pm 0.54	1.82 \pm 0.39
5	2.18	1.56	0.62	2.65	2.10	0.55	1.08	0.36	0.72	3.46	1.44	2.02	2.34 \pm 0.99	1.37 \pm 0.73	0.98 \pm 0.70
6	2.56	1.75	0.81	1.78	1.37	0.41	2.14	0.77	1.37	2.83	0.88	1.95	2.33 \pm 0.46	1.19 \pm 0.45	1.14 \pm 0.67
7	3.07	1.98	1.09	2.19	1.51	0.68	1.95	0.29	1.66	3.18	1.87	1.31	2.60 \pm 0.62	1.41 \pm 0.77	1.18 \pm 0.41
8	1.81	0.96	0.85	2.56	1.73	0.83	1.42	0.48	0.94	2.31	0.86	1.45	1.19 \pm 0.41	1.00 \pm 0.52	1.02 \pm 0.29
Sector B													2.12 \pm 0.63	1.24 \pm 0.19	1.08 \pm 0.10
9	1.44	0.87	0.57	0.89	0.42	0.47	2.23	1.21	1.02	2.91	0.81	2.10	1.87 \pm 0.89	0.83 \pm 0.32	1.04 \pm 0.75
10	1.28	0.76	0.52	1.08	0.40	0.68	1.59	0.63	0.96	1.75	0.43	1.32	1.43 \pm 0.30	0.56 \pm 0.17	0.87 \pm 0.35
11	2.04	1.73	0.31	1.25	1.02	0.23	3.11	1.14	1.97	2.56	1.70	0.86	2.24 \pm 0.79	1.40 \pm 0.37	0.84 \pm 0.80
12	1.79	1.21	0.58	0.48	0.33	0.15	2.01	0.76	1.25	1.17	0.67	0.50	1.36 \pm 0.69	0.74 \pm 0.36	0.62 \pm 0.46
13	1.66	0.93	0.73	1.46	0.80	0.66	0.98	0.23	0.75	2.15	0.75	1.40	1.56 \pm 0.48	1.38 \pm 0.57	0.89 \pm 0.35
Sector C													1.69 \pm 0.36	0.98 \pm 0.38	0.85 \pm 0.15
14	2.14	1.45	0.69	1.80	1.45	0.35	2.98	0.34	2.64	3.29	1.22	2.07	2.55 \pm 0.70	1.12 \pm 0.53	1.44 \pm 1.09
15	4.25	3.12	1.13	2.32	1.62	0.70	3.76	1.58	2.18	3.44	0.53	2.91	3.44 \pm 0.82	1.71 \pm 1.07	1.73 \pm 1.00
16	2.71	2.04	0.67	1.66	0.90	0.76	3.25	1.55	1.70	1.36	0.70	0.66	2.25 \pm 0.86	1.30 \pm 0.61	0.95 \pm 0.50
Sector D													2.75 \pm 0.62	1.38 \pm 0.30	1.37 \pm 0.39
Sector E 17	1.17	0.81	0.36	0.39	0.28	0.11	0.75	0.15	0.60	0.96	0.54	0.42	0.82 \pm 0.33	0.56 \pm 0.22	0.26 \pm 0.15
Mean \pm SD	2.78	1.92	0.86	1.96	1.37	0.59	2.49	0.82	1.67	2.76	1.10	1.67	2.26 \pm 1.16	1.25 \pm 0.56	1.08 \pm 0.58
	\pm 1.44	\pm 1.55	\pm 0.39	\pm 1.06	\pm 0.84	\pm 0.31	\pm 1.17	\pm 0.49	\pm 0.84	\pm 1.14	\pm 0.63	\pm 0.86			

Table 7. The percentage of particulate (P) and dissolved (D) metals to the total metals.

Seasons		Winter	Spring	Summer	Autumn
Metals					
Cu	P	38.65	41.52	42.59	40.54
	D	61.57	58.12	57.41	58.38
Zn	P	74.41	67.13	69.84	65.92
	D	25.66	33.37	30.05	34.29
Pb	P	65.4	66.06	31.53	62.57
	D	34.55	34.29	68.97	37.7
Cd	P	61.86	61.43	34.13	67.14
	D	39.18	37.62	65.65	32.86
Fe	P	70.87	66.61	36.96	69.88
	D	29.13	33.36	63.81	30.30
Mn	P	69.07	69.9	32.93	39.86
	D	30.93	30.10	67.07	60.51

In the present work, the concentrations of heavy metals studied agreed with those found in the literature. Table (9) shows that Cu and Zn concentrations in the present study were lower than those reported by Fahmy (1981) and Abo-El-Khair (1993) while Pb was higher than that of Abo-El-Khair (1993) and Cd fell within the range elsewhere.

Table 8. Correlation (r) between total (T), particulate (P) and dissolved (D) forms of metals in water of the area area of investigation during 2003.

Metals	Cu			Zn			Pb			Cd			Fe			Mn		
	T	P	D	T	P	D	T	P	D	T	P	D	T	P	D	T	P	D
Total	1			1			1			1			1			1		
Particulate	0.99	1		0.99	1		0.99	1		0.98	1		0.99	1		0.99	1	
Dissolved	0.99	0.96	1	0.98	0.98	1	0.97	0.93	1	0.97	0.92	1	0.97	0.95	1	0.98	0.97	1

Table 9. Comparison between the concentrations of Cu, Zn, Pb, Cd, Fe and Mn ($\mu\text{g/L}$) in different ecosystems and the present study.

Metals Area	Cu			Zn			Pb			Cd			Fe			Mn
	T	P	D	T	P	D	T		D	T	P	D	T	P	D	T
Suez Canal	1.97	0.78	1.19	7.22	5.04	2.06	2.03	1.12	0.90	0.43	0.22	0.22	26.1	15.53	10.62	2.26
Suez Canal	1.37	0.43	0.94	4.03	3.05	0.98	3.42	1.48	1.94	0.51	0.16	0.35	25.1	15.20	9.90	2.84
Gulf of Suez	2.72	0.94	1.83	7.11	2.43	4.68	1.77	0.64	1.13	0.74	0.19	0.55	--	--	--	1.78
Port Said	1.43	0.27	1.16	7.28	4.27	3.01	1.39	0.49	0.90	0.50	0.14	0.36	--	--	--	--
Damietta Estuary of the River Nile	12.47	9.07	3.4	32.8	9.2	13.6	---	---	---	0.29	0.21	0.08	--	--	--	--
Gulf of Suez	9.61	3.31	6.3	19.3	15.85	3.45	1.77	0.49	1.28	0.21	0.06	0.15	--	--	--	--
Rosetta Estuary of the River Nile	16.25	4.85	11.4	64.5	21.8	42.7	0.59	0.18	0.41	---	---	0.79	--	--	--	--

Heavy metals in sediments:

Table (10) shows heavy metal concentrations in the sediments of the Suez Canal during 2003. According to the local distribution of metals of the Suez Canal, station 3 showed the highest levels of Cu (63.30), Pb (46.44), Cd (5.12), Fe (2.89×10^3) and Mn (521.75) $\mu\text{g/g}$, while Zn (75.52) $\mu\text{g/g}$ was highest at station 2. Station 17 had the lowest values for all metals (Cu = 6.26, Zn = 12.84, Pb = 8.44, Cd = 1.85, Fe = 2.12×10^3 and Mn = 243.60 $\mu\text{g/g}$). This may reflect the high contributions of land-based activities in the northern part of the Suez Canal.

Table 10. Heavy metal concentrations ($\mu\text{g/g}$) in sediments collected from the area of investigation during 2003.

Metals Stations	CU	ZN	Pb	Cd	Fe x 10 ³	Mn
1	38.67	44.54	29.12	4.63	2.66	485.15
2	54.48	75.52	32.31	3.24	2.78	406.60
3	63.30	57.63	46.44	5.12	2.89	521.75
4	35.02	40.16	38.29	2.89	2.81	389.03
Sector A	47.87±13.31	54.46±15.88	36.54±7.62	2.97±1.07	2.79±0.1	450.63±63.20
5	25.11	36.73	27.56	1.72	2.55	298.25
6	31.21	37.41	21.78	2.56	2.42	336.10
7	42.64	48.79	36.89	3.25	2.73	376.85
8	29.52	32.37	15.24	1.43	2.61	352.90
Sector B	32.12±7.47	38.83±7.01	25.37±9.18	2.24±0.83	2.58±0.13	341.03±33.06
9	18.4	15.35	24.85	1.85	2.22	256.45
10	21.75	33.88	25.04	1.58	2.48	324.25
11	10.68	25.70	21.66	2.24	2.16	289.93
12	14.36	19.96	28.45	2.78	2.36	266.27
13	17.14	13.22	19.20	2.97	2.31	275.83
Sector C	15.98±2.67	21.62±8.36	23.84±3.54	2.28±0.59	2.31±0.12	282.55±26.39
14	42.13	47.15	34.72	3.04	2.79	267.08
15	49.41	56.90	43.37	3.65	2.85	412.46
16	36.95	31.46	26.50	2.78	2.63	386.12
Sector D	42.83±6.26	45.17±12.84	34.86±8.44	3.16±0.45	2.76±0.11	355.22±77.46
17 (Sector E)	12.31	20.44	18.10	1.85	2.12	243.60

Table (10) shows that mean concentrations of heavy metals in the sediments in the Suez Canal were somewhat higher in the northern parts (sector A) with decreases in the following order of the southern part (sector D) > the middle part (sectors B and C) > Sinai side (sector E). It is clear that all metals studied showed a common trend of increase toward the northern part of the Suez Canal especially at station 3 that receives quantities of municipal and industrial wastewaters from many outlets as well as from ships crossing the canal to or from the Mediterranean. All these sources can have an immediate effect on metal concentrations of marine sediments (Mohapatra, 1988). Rajkumar *et al.* (1992) reported that the metals entering marine coastal areas became associated with sediments, especially the smaller particles, with the sediments in the northern part of the Suez Canal comprised of light gray muddy sands of the Nile origin (UNEP, 1997). Nichol森 and Moore, (1981) observed that a major portion of metal inputs entered the marine systems in the form of metals rich of finally divided particulate matter, which precipitated on encountering high electrolyte concentrations. The relatively high concentrations of heavy metals in the sediments at the southern part of the Suez Canal may be explained by the fact that this part is affected by large amount of invading water coming from the Suez Bay, which is largely loaded with oil and industrial effluents.

CONCLUSION AND RECOMMENDATIONS

From the present study, it can be concluded that heavy metals exhibited clear variations in their distribution between the particulate and dissolved forms, where the concentration of the particulate forms were higher than the dissolved phases. Land-based activities are the main pollution sources in the investigated area. Concentrations of particulate and dissolved heavy metals viz: Cu, Zn, Pb, Cd, Fe and Mn the Suez Canal can be divided into three main areas, the southern part (sector D) that is affected by the invading water coming from the Suez Bay, where there are many sources of pollution. The middle part of the Canal, including Bitter Lakes and Lake Timsah (sectors B and C) that are affected by agricultural effluents and sewage discharge. The northern part (sector A), possesses high sources of activities. Thus it is obligatory for the cities within boundaries of the Suez Canal and national organizations of environmental protection to introduce control management plans to protect the Suez Canal. This might include the supply of treatment units to the industrial companies and to all kinds of vehicles, as well as prevention of discharging waste-waters in the area. Moreover, rapid, effective techniques should be applied to the disposed effluents.

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