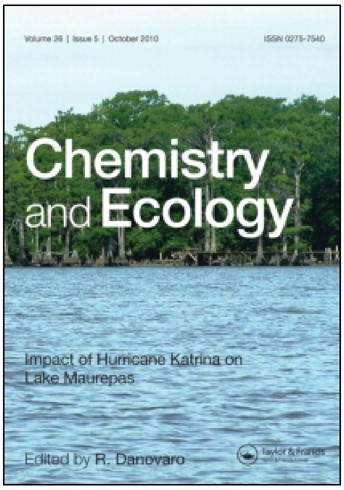

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Assessment of heavy metals among suspended particulates and dissolved phases in Suez Canal water

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Assessment of heavy metals among suspended particulates and dissolved phases in Suez Canal water

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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 concentrations of particulate metals viz: Zn, Pb, Cd, Fe and Mn were high as compared to the dissolved form. Dissolved copper showed the highest percentage of total copper rather than particulate. The particulate forms of Pb, Cd, Fe and Mn had always-higher concentrations than the dissolved forms during the course of study except at 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 μg/L. These high concentrations may be attributed to the high activities, particularly, loading and unloading operations at Port Said harbour, industrial effluents and domestic drainage of Port Said city. On the other hand, Sinai side could be considered as reference site, as it is almost clean 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 μg/L for particulate and dissolved metals respectively.

Keywords: Speciation; Heavy metals; Suspended particulate; Seawater; Sediments; Suez Canal

1. Introduction

Suez Canal is, actually, the lonely canal linking between the Mediterranean Sea and 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, since it acts as a big navigation route. Oil pollution due to 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 affect directly or indirectly the marine life of the canal. Infrastructures established on the canal coasts are land-based sources of these types of pollution. All refuses coming from the different sources are discharged

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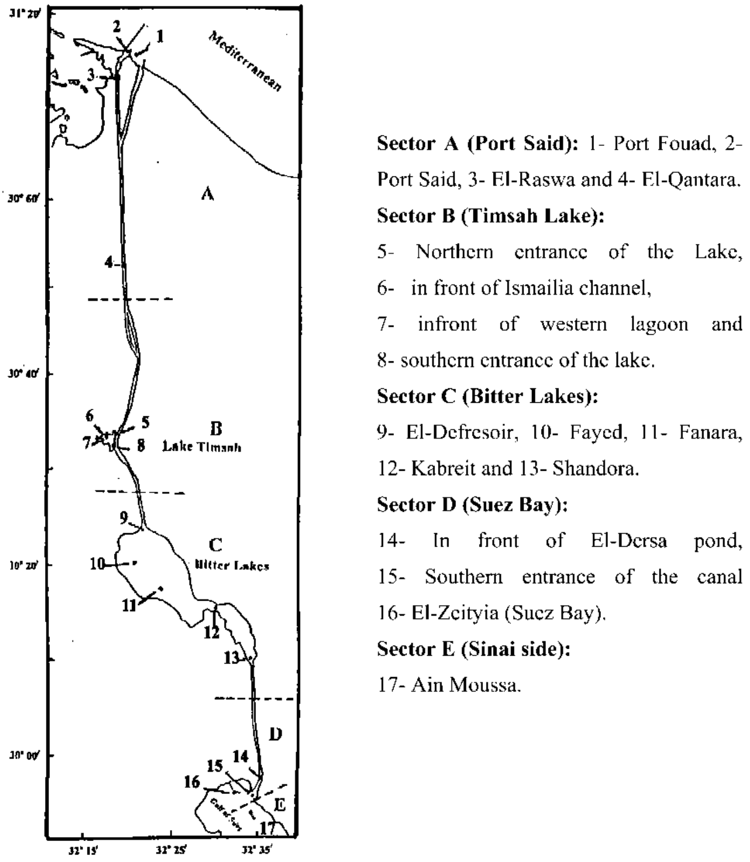
directly or indirectly into the Suez Canal. These refuses contain large amounts of chemical residues especially metals and hydrocarbons [1]. In a natural aquatic system, metals may be distributed among dissolved, colloidal or particulate fractions because of such reactions as precipitation and coprecipitation or complexation with organic or inorganic legands. In some cases, the distribution may depend on the presence of more than one oxidation state for the metal [2]. The aim of this work is to assess the distribution of heavy metals among suspended particulates and dissolved phases in the Suez Canal water.

2. Materials and methods

2.1 *Sampling*

Surface (0–0.5 m depth) water samples were collected seasonally during February, May, August and November 2003 using Nansen bottles from seventeen stations divided into four sectors (A, B, C and D) between Suez and Port-Said provinces (figure 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- infront 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.

Figure 1. Map of the Suez Canal showing the selected sectors and stations.

2.2 *Procedures*

After collecting the samples and filtering through 0.45 µm fiberglass paper [3]; the filtered mass was kept for analysis while the filtrate was treated with ammonium pyrralodine dithiocarbamate (APDC) to complex the heavy metals. After shaking well, methyl isobutyl ketone (MIBK) was used for extraction [4]. The particulate for each sample was dissolved in 3 mL of concentrated HNO_3 plus H_2O_2 [5] and treated as the filtrate. Measurements of the heavy solution for the heavy metals were carried out using Perkin-Elmer 2380 atomic absorption spectrometer. Blanks were provided through all determinations. The precision and accuracy for the method of metals determination in water was checked by replicate measurements of the studied metals in seawater sample. Precision was found satisfactory which was in the range of 9.0–19.6% for all metals. The recovery values of metals analysis were between 82% and 93%.

3. Results and discussion

3.1 *Regional distribution of heavy metals*

Suez Canal receives various land-based sources of wastes discharging 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 higher levels of heavy metals, while the minimum levels were recorded at Sinai side (tables 1 and 2). At 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) µg/L respectively. This part is affected by the invading water coming from the Suez Bay, where there are many sources of pollution as domestic drainage of Suez city, industrial wastes of Fertilizer Company, power stations and oil refineries. The middle part (sectors B and C), near Ismailia, shows slightly high 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) µg/L respectively. This is probably due to agricultural effluents, shipyard of the Suez Canal and sewage discharge. The northern part of the Suez Canal at Port Said (sector A) has mean concentration 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) µg/L, respectively; where this part possesses high sources of activities, such as loading and unloading operations at Port Said harbor, particularly the industrial effluents and domestic drainage of Port Said city. Sinai side (sector E) could be used as control, as it is almost clean 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 µg/L for particulate and dissolved metals respectively.

3.2 *Seasonal distribution of heavy metals*

Copper. The regional variation of copper had its maximum values (2.77, 1.15 and 1.61 µg/L) during spring for total, particulates and dissolved copper respectively (table 3). Their corresponding minimum values (1.62, 0.69 and 0.93 µg/L) were recorded during 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 copper attained the highest level of total copper rather than the particulate (table 4). In seawater, no more than 10% of total Cu may be bound to humic acids [6]. Moore [7] showed that, desorption of

Table 1. Annual mean of Cu, Zn and Pb (μg/L) in different types of surface seawater of the Suez Canal during 2003.

Metals	Cu			Zn			Pb		
Stations	T	P	D	T	P	D	T	P	D
1	3.56 ± 0.74	1.36 ± 0.32	2.21 ± 0.43	9.98 ± 3.68	7.03 ± 2.42	2.95 ± 1.50	2.57 ± 0.55	1.51 ± 0.85	1.06 ± 0.47
2	4.41 ± 1.84	2.04 ± 0.80	2.38 ± 1.11	13.95 ± 4.38	9.79 ± 2.09	4.15 ± 2.32	3.61 ± 0.55	2.10 ± 0.69	1.52 ± 0.59
3	3.94 ± 1.16	1.37 ± 0.35	2.57 ± 0.88	16.13 ± 2.32	10.60 ± 4.11	3.07 ± 1.70	3.48 ± 1.16	2.10 ± 1.33	1.38 ± 0.77
4	2.18 ± 0.36	0.95 ± 0.29	1.23 ± 0.19	9.55 ± 3.07	7.02 ± 2.03	2.53 ± 1.50	2.09 ± 0.63	1.15 ± 0.51	0.94 ± 0.51
Sector A	3.52 ± 0.83	1.43 ± 0.39	2.10 ± 0.52	12.40 ± 3.18	8.61 ± 1.86	3.17 ± 0.69	2.94 ± 0.73	1.72 ± 0.47	1.23 ± 0.27
5	1.5 ± 0.83	0.80 ± 0.27	0.67 ± 0.34	5.68 ± 1.56	3.61 ± 0.99	2.07 ± 0.57	1.61 ± 0.61	1.03 ± 0.60	0.58 ± 0.22
6	1.98 ± 0.55	0.86 ± 0.30	1.12 ± 0.37	6.79 ± 2.63	4.85 ± 2.54	1.94 ± 0.90	1.81 ± 0.73	0.93 ± 0.55	0.88 ± 0.41
7	2.47 ± 0.60	0.73 ± 0.17	1.74 ± 0.72	7.35 ± 2.55	4.65 ± 2.17	2.71 ± 0.53	2.58 ± 0.39	1.31 ± 0.48	1.28 ± 0.30
8	1.33 ± 0.33	0.70 ± 0.27	0.63 ± 0.20	4.52 ± 1.66	3.28 ± 1.56	1.24 ± 0.26	1.67 ± 0.41	1.01 ± 0.56	0.66 ± 0.181
Sector B	1.82 ± 0.45	0.77 ± 0.06	1.04 ± 0.41	6.09 ± 1.25	4.10 ± 0.77	1.99 ± 0.60	1.92 ± 0.45	1.07 ± 0.17	0.85 ± 0.31
9	1.07 ± 0.20	0.47 ± 0.09	0.60 ± 0.18	4.23 ± 2.06	3.02 ± 1.58	1.21 ± 0.92	1.81 ± 0.29	1.09 ± 0.48	0.72 ± 0.30
10	1.44 ± 0.32	0.73 ± 0.28	0.71 ± 0.30	4.32 ± 1.51	3.35 ± 1.34	0.97 ± 0.25	2.12 ± 0.50	1.34 ± 0.45	0.78 ± 0.33
11	1.29 ± 0.19	0.59 ± 0.18	0.71 ± 0.10	4.83 ± 1.07	3.50 ± 0.96	1.33 ± 0.16	1.40 ± 0.36	0.80 ± 0.29	0.60 ± 0.23
12	1.89 ± 0.35	0.71 ± 0.20	1.17 ± 0.40	3.92 ± 1.71	2.58 ± 1.40	1.34 ± 0.49	1.71 ± 0.40	0.99 ± 0.41	0.72 ± 0.44
13	1.23 ± 0.28	0.51 ± 0.14	0.73 ± 0.23	4.30 ± 1.46	2.68 ± 1.01	1.62 ± 0.46	1.58 ± 0.37	0.94 ± 0.36	0.64 ± 0.36
Sector C	1.38 ± 0.28	0.60 ± 0.10	0.78 ± 0.20	4.32 ± 0.33	3.03 ± 0.40	1.29 ± 0.24	1.72 ± 0.27	1.03 ± 0.20	0.69 ± 0.07
14	2.85 ± 0.28	1.18 ± 0.15	1.66 ± 0.20	9.78 ± 4.22	7.35 ± 3.64	2.43 ± 1.05	2.73 ± 0.64	1.37 ± 0.54	1.36 ± 0.66
15	2.59 ± 0.76	1.06 ± 0.29	1.54 ± 0.50	11.46 ± 4.54	7.80 ± 3.28	3.67 ± 1.29	3.46 ± 1.05	2.12 ± 0.09	1.34 ± 0.62
16	1.85 ± 0.27	0.59 ± 0.11	1.25 ± 0.10	9.35 ± 3.02	6.77 ± 2.19	2.57 ± 1.16	1.90 ± 0.44	0.98 ± 0.40	0.92 ± 0.49
Sector D	2.43 ± 0.42	0.94 ± 0.25	1.48 ± 0.13	10.20 ± 1.12	7.31 ± 0.52	2.89 ± 0.68	2.70 ± 0.78	1.49 ± 0.58	1.21 ± 0.25
Sector E 17	0.72 ± 0.17	0.16 ± 0.08	0.56 ± 0.10	3.08 ± 1.23	2.14 ± 0.83	0.94 ± 0.42	0.85 ± 0.16	0.31 ± 0.14	0.54 ± 0.15
Mean ± SD	2.13 ± 0.44	0.87 ± 0.18	1.26 ± 0.27	7.22 ± 3.95	5.04 ± 2.97	2.06 ± 0.97	2.03 ± 0.83	1.12 ± 0.54	0.90 ± 0.31

T = Total, P = Particulate and D = Dissolved.

Table 2. Annual mean of Cd, Fe and Mn (μg/L) in different types of surface seawater of the Suez Canal during 2003.

Metals	Cd			Fe			Mn		
Stations	T	P	D	T	P	D	T	P	D
1	0.65 ± 0.64	0.26 ± 0.14	0.39 ± 0.58	32.19 ± 10.85	20.06 ± 3.81	12.13 ± 8.79	3.13 ± 0.70	1.53 ± 0.84	1.60 ± 0.58
2	0.83 ± 0.67	0.44 ± 0.20	0.39 ± 0.54	47.33 ± 12.66	30.15 ± 15.71	17.14 ± 12.12	4.45 ± 0.58	2.32 ± 1.32	2.13 ± 1.80
3	0.74 ± 0.43	0.38 ± 0.15	0.37 ± 0.41	51.00 ± 9.97	29.35 ± 13.06	21.66 ± 3.00	4.88 ± 1.27	2.73 ± 1.67	2.16 ± 1.58
4	0.55 ± 0.37	0.32 ± 0.18	0.23 ± 0.21	26.71 ± 3.57	14.31 ± 4.72	12.40 ± 6.60	3.17 ± 1.08	1.79 ± 0.96	1.39 ± 0.58
Sector A	0.69 ± 0.12	0.35 ± 0.08	0.35 ± 0.08	39.31 ± 11.70	23.49 ± 7.62	15.83 ± 4.52	3.91 ± 0.89	2.09 ± 0.54	1.82 ± 0.39
5	0.42 ± 0.37	0.23 ± 0.17	0.19 ± 0.22	24.63 ± 6.51	12.93 ± 3.12	11.70 ± 4.84	2.34 ± 0.99	1.37 ± 0.73	0.98 ± 0.70
6	0.31 ± 0.24	0.14 ± 0.11	0.18 ± 0.16	30.52 ± 9.62	10.73 ± 9.38	11.79 ± 9.22	2.33 ± 0.46	1.19 ± 0.45	1.14 ± 0.67
7	0.62 ± 0.46	0.32 ± 0.14	0.31 ± 0.33	25.61 ± 4.16	13.81 ± 8.63	11.80 ± 8.78	2.60 ± 0.62	1.41 ± 0.77	1.18 ± 0.41
8	0.47 ± 0.33	0.33 ± 0.28	0.13 ± 0.06	18.51 ± 7.69	12.06 ± 4.60	6.45 ± 5.26	1.19 ± 0.41	1.00 ± 0.52	1.02 ± 0.29
Sector B	0.46 ± 0.13	0.26 ± 0.09	0.20 ± 0.08	24.82 ± 4.93	12.38 ± 1.31	10.44 ± 2.66	2.12 ± 0.63	1.24 ± 0.19	1.08 ± 0.10
9	0.36 ± 0.28	0.14 ± 0.11	0.22 ± 0.27	16.80 ± 4.75	9.30 ± 2.35	7.50 ± 5.73	1.87 ± 0.89	0.83 ± 0.32	1.04 ± 0.75
10	0.32 ± 0.26	0.14 ± 0.09	0.18 ± 0.18	24.29 ± 3.59	11.96 ± 1.07	12.41 ± 4.60	1.43 ± 0.30	0.56 ± 0.17	0.87 ± 0.35
11	0.31 ± 0.26	0.15 ± 0.14	0.16 ± 0.14	16.63 ± 8.24	8.59 ± 4.20	8.04 ± 5.15	2.24 ± 0.79	1.40 ± 0.37	0.84 ± 0.80
12	0.37 ± 0.18	0.23 ± 0.18	0.14 ± 0.08	17.86 ± 2.51	10.93 ± 1.68	7.17 ± 3.29	1.36 ± 0.69	0.74 ± 0.36	0.62 ± 0.46
13	0.29 ± 0.17	0.13 ± 0.08	0.17 ± 0.15	13.05 ± 5.18	8.35 ± 2.43	4.70 ± 3.05	1.56 ± 0.48	1.38 ± 0.57	0.89 ± 0.35
Sector C	0.33 ± 0.03	0.16 ± 0.04	0.17 ± 0.03	17.73 ± 4.09	9.83 ± 1.56	7.69 ± 2.80	1.69 ± 0.36	0.98 ± 0.38	0.85 ± 0.15
14	0.55 ± 0.43	0.26 ± 0.21	0.30 ± 0.38	30.55 ± 9.43	20.35 ± 12.75	10.21 ± 9.19	2.55 ± 0.70	1.12 ± 0.53	1.44 ± 1.09
15	0.69 ± 0.57	0.29 ± 0.17	0.40 ± 0.42	33.79 ± 10.29	20.67 ± 7.30	3.12 ± 10.24	3.44 ± 0.82	1.71 ± 1.07	1.73 ± 1.00
16	0.39 ± 0.30	0.20 ± 0.14	0.19 ± 0.19	25.17 ± 5.82	16.27 ± 3.83	8.90 ± 6.15	2.25 ± 0.86	1.30 ± 0.61	0.95 ± 0.50
Sector D	0.54 ± 0.15	0.25 ± 0.05	0.30 ± 0.11	29.84 ± 4.35	19.10 ± 2.45	7.41 ± 3.77	2.75 ± 0.62	1.38 ± 0.30	1.37 ± 0.39
Sector E17	0.14 ± 0.08	0.06 ± 0.4	0.09 ± 0.04	8.98 ± 2.86	6.29 ± 2.01	3.44 ± 2.32	0.82 ± 0.33	0.56 ± 0.22	0.26 ± 0.15
Mean ± SD	0.43 ± 0.21	0.21 ± 0.10	0.22 ± 0.10	26.10 ± 5.99	15.53 ± 4.38	10.62 ± 6.32	2.26 ± 1.16	1.25 ± 0.56	1.08 ± 0.58

Table 3. Seasonal variation of heavy metals (μg/L) in different types of surface seawater of the Sues Canal during 2003.

Seasons		Metals					
		Cu	Zn	Pb	Cd	Fe	Mn
Winter	T	2.29 ± 1.08	9.00 ± 3.62	1.98 ± 0.63	0.19 ± 0.10	27.70 ± 12.46	2.78 ± 1.44
	P	0.88 ± 0.52	6.70 ± 2.62	1.29 ± 0.52	0.12 ± 0.08	19.63 ± 9.66	1.92 ± 11.55
	D	1.41 ± 0.78	2.31 ± 1.22	0.68 ± 0.28	0.076 ± 0.03	8.07 ± 3.08	0.86 ± 0.39
Spring	T	2.77 ± 1.70	10.10 ± 6.08	2.77 ± 1.19	0.21 ± 0.11	28.51 ± 14.90	1.96 ± 1.06
	P	1.15 ± 0.68	6.78 ± 4.13	1.83 ± 0.90	0.13 ± 0.09	18.99 ± 12.72	1.37 ± 0.84
	D	1.61 ± 1.10	3.37 ± 2.27	0.95 ± 0.38	0.08 ± 0.03	9.51 ± 5.95	0.59 ± 0.31
Summer	T	1.62 ± 0.66	6.40 ± 3.35	2.03 ± 0.84	0.92 ± 0.44	30.84 ± 10.70	2.49 ± 1.17
	P	0.69 ± 0.29	4.47 ± 2.58	0.64 ± 0.32	0.31 ± 0.18	11.40 ± 2.62	0.82 ± 0.49
	D	0.93 ± 0.43	1.92 ± 1.03	1.40 ± 0.60	0.60 ± 0.35	19.68 ± 8.95	1.67 ± 0.84
Autumn	T	1.85 ± 1.00	4.90 ± 2.71	1.91 ± 0.77	0.56 ± 0.18	17.33 ± 8.39	2.76 ± 1.14
	P	0.75 ± 0.43	3.23 ± 1.75	1.19 ± 0.50	0.38 ± 0.15	12.11 ± 6.35	1.10 ± 0.63
	D	1.08 ± 0.60	1.68 ± 1.15	0.72 ± 0.37	0.18 ± 0.07	5.22 ± 3.70	1.67 ± 0.86

copper from sediments is enhanced by increasing salinity and the concomitant competition for binding sites with the chloride ion.

Zinc. The regional variation of zinc had its maximum values (10.10, 6.78 and 3.37 μg/L) during spring for total, particulates and dissolved zinc, respectively (table 3). Their respective minimum values of 4.90, 3.23 and 1.68 μg/L were recorded during autumn. Spring exhibited the maximum mean levels for all three forms of zinc and particulate zinc was dominant form for all seasons and comprised about 65.92% to 74.41% of the total zinc (table 4). Owing to the higher zinc input during spring, which binds readily with many organic ligands, particularly in presence of nitrogen or sulfur donor atoms, this may explain the higher particulate zinc than dissolved zinc. Moore [7] indicated that the binding of zinc to suspended particulates depends on pH and Eh conditions, and the input of anthropogenically derived zinc.

Lead. The regional variation of Pb had its maximum values (2.77, 1.83 and 0.95 μg/L) during spring for total, particulates and dissolved Pb, respectively (table 3). Their minimum values were 1.91 μg/L for total Pb during autumn, 0.64 μg/L for particulate Pb during summer

Table 4. The percentage of particulates (P) and dissolved metals (D) to the total metal concentrations during 2003.

Metals		Seasons			
		Winter	Spring	Summer	Autumn
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

and 0.684 μg/L for dissolved Pb during winter. The relative decrease in Pb concentration in winter may be attributed to the relative decrease in decomposition rate of organic matter with lower temperature [8, 9]. Table 4 shows that particulate Pb was dominant at all seasons except during summer, where dissolved Pb constituted a major rate (68.97%) of total lead. Summer characterized by high salinity accompanied by high chloride ion [10], where lead typically desorbs from sediments and suspended solids in estuaries owing to competition with chlorides, producing an appreciable increase in soluble lead in water column [11].

Cadmium. The regional variation of Cd had its maximum values (0.92 and 0.604 μg/L) during summer for total and dissolved and 0.376 μg/L for particulate Cd during autumn, while their minimum values of 0.194, 0.12 and 0.076 μg/L where reported during winter for total, particulate and dissolved Cd, respectively (table 3). Therefore, the particulate Cd was the dominant form for all seasons but only during summer season and the dissolved Cd constituted a major percentage (65.65%) of total Cd (table 4). As salinity increased during summer, Cd concentration increased also. Zirino and Yamamoto [12] and Abdelmoneim and Fattouh [13] indicated that at higher salinities, Cd interacts primarily with chloride ions, while reverse happened for particulate Cd.

Iron. 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 (table 3). 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 4 shows that the particulate forms had high concentrations than the dissolved forms during the course of study except for summer season. Only during summer, dissolved form of Fe constituted a major percentage (63.81%) of total Fe. This may be explained by the fact that in summer, oxygen concentration in water sediment interface decreases to almost zero. This leads to reduction of Fe^{3+} to soluble Fe^{2+}, which is then transported upwards in the water column [7].

Manganese. The total and particulate Mn had their maximum regional values (2.78 and 1.92 μg/L) during winter, while the dissolved form showed maximum value (1.67 μg/L) during summer and autumn (table 3). 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 4). In summer, the depletion of oxygen at the water-sediment interface causes the reduction of Mn^{4+} to soluble Mn^{2+}, which is 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 reduction in the water column, whereas soluble Fe is supplied by reduction in the sediment [7].

3.3 *Statistical analysis*

The presented data show that the metal exhibited clear differences in their distribution between particulate and dissolved forms. Most particulate metals exhibited high concentration range than that of the dissolved metals. However, both particulate and dissolved forms show high significant correlation with each other and with total metals (table 5). This may indicate that the distribution of metals in different phases is governed by interaction of several variables: these include the suspended matter loads of the effluents, their outflow rate concentration and

Table 5. Correlation (r) between total (T), particulate (P) and dissolved (D) forms of metals in water of the area of investigation during 2003.

Metals	Cu			Zn			Pb		
Forms of metals	T	P	D	T	P	D	T	P	D
Total	1.0			1.0			1.0		
Particulate	0.99	1.0		0.99	1.0		0.99	1.0	
Dissolved	0.99	0.96	1.0	0.98	0.98	1.0	0.97	0.93	1.0
Metals	Cd			Fe			Mn		
Forms of metals	T	P	D	T	P	D	T	P	D
Total	1.0			1.0			1.0		
Particulate	0.98	1.0		0.99	1.0		0.99	1.0	
Dissolved	0.97	0.92	1.0	0.97	0.95	1.0	0.98	0.97	1.0

physical forms of the metal in the effluent, stratification and stability of seawater and the current velocity and pattern [14]. Statistical analysis indicates 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 can be due to adsorption of zinc by hydrous iron oxide [15]. However, the obtained correlation ($r = 0.87$ and 0.92) between zinc and copper is due insolubility of both metals in the oxidized state and forming sulfides in reducing conditions [16]. The positive correlation between copper and manganese ($r = 0.91$ and 0.96) indicates that copper is mostly adsorbed by amorphous manganese oxyhydroxide particles [17]. In the present work, concentration of heavy metals studied coincided with those found in the literature. Table 6 shows that Cu and Zn concentrations in the present study are lower than those reported by Abo El-Khair [18] while Pb is higher than that of Abo-El-Khair [18] while Cd lies within the range elsewhere.

3.4 *Heavy metals in sediments*

Table 7 shows heavy metals 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) $\mu g/g$, while Zn (75.52) $\mu g/g$ at station 2. Station 17 had the lowest value of all metals ($Cu = 6.26$, $Zn = 12.84$, $Pb = 8.44$, $Cd = 1.85$, $Fe = 2.12 \times 10^3$ and $Mn = 243.60\, \mu g/g$). This may reflect the high contribution of land-based activities in the northern part of the Suez Canal. Table (7) shows that mean concentrations of heavy metals in the sediments in the Suez Canal was somewhat high at the northern parts (sector A) and 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 towards the northern part of the Suez Canal especially at station 3, where it receives quantities of municipal and industrial wastewaters from many outlets as well as ships crossing the canal to or from the Mediterranean. All these sources can have an immediate effect on metal concentrations of marine sediments [19]. Rajkumar *et al.* [20] reported that the metals entering marine coastal areas become associated with sediments, especially the smaller particles, the sediments in the northern part of the Suez Canal comprised light gray muddy sands of the Nile origin [21]. Nicholsen and Moore [22] observed that a major portion of metals input enters the marine systems in the form of metals rich of finally divided particulate matter, which precipitates on encountering high electrolyte concentrations. The relatively high concentrations of heavy metals in the sediments at the southern part of the

Table 6. Correlation (r) between total (T), particulate (P) and dissolved (D) forms of metals in water of the area of investigation during 2003.

Metals	Cu			Zn			Pb			Cd			Fe			Mn			
Area	T	P	D	T	P	D	T	P	D	T	P	D	T	P	D	T	P	D	References
Suez Gulf	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	1.25	1.08	Present study
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	1.73	1.11	[23]
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	0.65	1.13	[24]
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	–	–	–	–	–	–	[13]
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	–	–	–	–	–	–	[25]
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	–	–	–	–	–	–	[18]

Table 7. Heavy metal concentrations (μg/g) in sediments collected from the area of investigation during 2003.

Stations	Cu	Zn	Pb	Cd	Fe × 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

Suez Canal may be explained by the fact that this part is affected by large amount of invading water coming from the Suez Bay, largely loaded with oil and industrial effluents.

4. Conclusion

This study suggests that heavy metals exhibit a clear variation in their distribution between the particulate and dissolved forms, where the concentration of the particulate forms are higher than the dissolved phases. The land-based activities are the main pollution sources in the investigated area. Concerning the concentration of particulate and dissolved heavy metals viz: Cu, Zn, Pb, Cd, Fe and Mn the Suez Canal can be divided into three main parts, the southern part (sector D) 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) is 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 induce 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 shedding wastes-water to the area. Moreover quick fine technique should be applied to the disposed effluents.

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