INVESTIGATING THE IMPACT OF FLOW CONDITIONS ON METAL CONTENTS IN NILE BED SEDIMENTS

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ABSTRACT

Many pollutants entering the aquatic environment are insoluble in water and are bound to sediment particles in the water column.

This study was initiated in order to evaluate the seasonal changes in metal contents of the Nile bed sediments and to determine the main factors controlling its distribution. Two groups of bed samples were collected from ten sites upstream the Nile Barrages during February and August 2007. These samples were analyzed to determine their total metal contents, pH and organic matter contents. The results revealed that the metal concentrations were higher in February than those sampled in August. The results also showed that metal contents are directly correlated to organic matter in February. The correlation matrix between most metals and iron and manganese suggested that, the two geochemical phases of iron and manganese oxide act as active support to the adsorption of metal ions. Environmental assessment of sediments pollution by heavy metals was carried out using geo-accumulation index and Enrichment factor. The results of the geo-accumulation index revealed that, at the samples taken from the upstream of the Delta Barrage (Damietta and Rosetta Branches) and Edfina Barrage are strongly polluted with metals in August while, they are moderately polluted by metals in February. Based on the Enrichment Factor calculation, the sites upstream the Nile Barrages are not contaminated by metals except for Fe, Ni and Mn upstream Esna Barrage in February. However, in August, the area upstream Assuit Barrage is contaminated by Fe and Ni. The study concluded that the organic matter and flow conditions are considered main factors for heavy metal distribution in Nile bed sediments. It is recommended to apply metal speciation analysis on the Nile bed sediment to provide more information on its biological availability.

Keywords: Nile River, Bed sediment, Pollutants, Heavy metals, Geo-accumulation index and Enrichment factor.

1. INTRODUCTION

Bed sediment is a reservoir for heavy metals and is regarded as serious pollutants of aquatic ecosystems due to their environmental persistence, toxicity and ability to be incorporated into food chains. The concentration of metals in any sediment sample depends upon many interacting factors such as, sources of sedimentary materials, the processes that led to the presence of suspended metal in the water column, the hydraulic and chemical factors.

Sediment is frequently analyzed in order to identify the sources of trace metal in the aquatic environment due to its high accumulation rates (Forstner et al., 1981). Sediment analysis determines the contaminant contents that are adsorbed by the particulate matter that can not be detected by water analysis. River bed sediment and suspended particles are the major carriers for the transport of particle-bound metals in aquatic systems. They are more sensitive indicators to contamination. Many investigations proved that sediment analysis is useful in detecting pollution sources. This is attributed to the fact that sediment is useful in the assessment of the degree of pollution of water bodies due to the ease of sampling, handling and analysis. Contaminated sediments pose a risk to the environment in two basic mechanisms: (1) ecological risk to aquatic and piscivorous animals and (2) toxic risks on terrestrial habitat when the contaminated area is dredged and placed on land (Khan et al., 2000).

Many pollutants entering the aquatic environment are insoluble in water and are bound to sediment particles in the water column. Contaminated sediments might be toxic to aquatic life (Swartz et al., 1985) or, might cause long term chronic effects through bioaccumulation. Even with the control of point and non-point sources of water pollution in river, the sediment contaminated with metals and other pollutants are sources of pollution to overlying waters and benthic food chains (Lyman et al., 1987). As long as the sediment remains undisturbed, most of the trace metals are fixed to it (Peterson et al., 1995). However, if these anoxic sediments are exposed to an oxic environment the minerals containing sulfides might be re-oxidized releasing trace elements to the aqueous phase or the transformation to the solid phase to more bio-form (Khalid et al., 1978). Förstner et al., (1986) pointed out four main factors (pH, redox conditions, organic complexation and salinity) which influence the mobility and bioavailability of sediment-bound metals.

This study was thus initiated with the objective of determining the seasonal changes in the heavy metals contents. This paper reports the concentrations of nine heavy metals (Al, Cd, Cr, Cu, Fe, Mn, Ni, Zn and Pb) as well as the value of pH and the percentage of organic matter. Concentrations of heavy metals pollutants are also compared with Canadian guidelines. The obtained results from this study would most probably serve as a baseline for determining the sediment pollution status in the Nile River.

2. MATERIALS AND METHODS

2.1. Study Area and Sampling

Ten sediment samples were collected along the Nile River at the upstream of the Nile Barrages as well as the area upstream and downstream Khour Sail Aswan drain (mixed contaminants) and one point at Km 7.7 as reference point (Table 1 and Figure 1) during low and high flow conditions (February and August 2007). Superficial sediment samples were collected using a stainless steel Ponar grab sampler.

Table (1): Sediment Sampling Site

Code	Site Name	Distance from Aswan High Dam (Km)
RP	Reference point	7.7
S1	US Khour El Sail Drain	9.8
S2	DS Khour El Sail Drain	10.0
S3	US Esna Barrage	168.0
S4	US Naga Hamadi Barrage	361.0
S5	US Assuit Barrage	547.0
S6	US Delta Barrage at Damietta	957.0
S7	US Delta Barrage at Rosetta	957.0
S8	US Damietta Dam	1180.0
S9	US Edfina Barrage	1156.5

US: upstream, DS: downstream

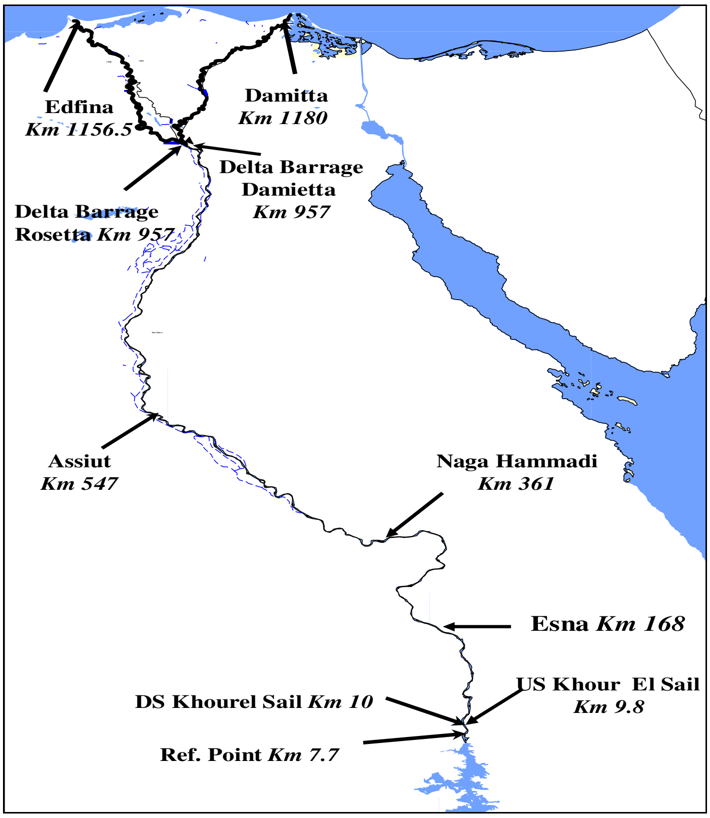

Fig. (1): Sampling sites along the Nile River

2.2. Laboratory Analysis

The samples were transferred into labeled polyethylene bags, and stored in the laboratory at 4 °C to inhibit any biological activity until preparation of analysis. The samples were then analyzed for total heavy metals content, pH and organic matter according to the following procedures:

The sediment pH was determined by mixing dry sediment with distilled water (Hendershot, 1993). Organic matter was determined by Walkley and Black method (Schnitzer, 1982). Heavy metals were digested by aqua regia and the solution of the digested samples was analyzed using ICP-MS method (Binning and Baird, 2001).

2.3. Indices Calculations

2.3.1. Geo-Accumulation Index (I_{geo})

The index of geo-accumulation (I_{geo}) is a measure of bed sediment contamination. It determines the contamination by comparing current metal contents with pre-industrial levels (Müller, 1981). The values of the geo-accumulation index can be defined as follows:

$$Igeo = \log_2 C_n/1.5\ B_n \qquad (1)$$

where:

C_n expresses the metal concentration of the element n

$B_{n,}$ is the geochemical background value

The content is multiplied by 1.5 in order to consider the natural fluctuations of a given substance and the anthropogenic influences.

Müller (1981) has distinguished 6 classes of the geo-accumulation index in order to indicate the degree of pollution as follow:

Class	Value	Quality of sediment
0	$I_{geo} \leq 0$	Unpolluted
1	$0 < I_{geo} < 1$	Unpolluted to moderately polluted
2	$1 < I_{geo} < 2$	Moderately polluted
3	$2 < I_{geo} < 3$	Moderately to strongly polluted
4	$3 < I_{geo} < 4$	Strongly polluted
5	$4 < I_{geo} < 5$	Strongly to extremely polluted
6	$5 < I_{geo}$	Extremely polluted

2.3.2. Enrichment Factor (Ef)

The enrichment factor is relative to the content of Al as a reference element. It was calculated, here, according to Gonzalez et al., (2000):

$$EF = (X_i)/(X_o): (Al_i)/(Al_o) \quad (2)$$

where:

(X_i); (Al_i): concentrations of element X and reference element Al at sampling station i

(X_o); (Al_o): background concentrations of element X and reference element Al.

2.4. Statistical Analysis

Correlation matrix and t-test sample were applied to study the seasonal variation and the behavior of the metal contents and their correlations in the bed sediments using Minitab 12 Software.

3. RESULTS AND DISCUSSION

3.1. Seasonal Variation of pH, Organic Matter and Heavy Metals Content

The results of the analysis and the executed computations were tabulated and represented as follows:

The pH values in bed sediments of Nile River upstream barrages during February and August 2007 periods are listed in Table (2). It ranged between 7.48 and7.96 and 7.36 and 7.95 with mean value of 7.76 and 7.69 in February and August, respectively. The pH values indicated that the bottom sediment is slightly alkaline. It is worth to mention that, the variation of the pH value influences the release or adsorption of each metal into the sediment fraction (Smith, 1994). The percentage of organic matter in bed sediments upstream Nile Barrages differed widely from site to site and from season to season. It ranged between 0.44 and 4.68% and 0.17 and 3.02% with mean value of 1.95 and 0.96% in February and August, respectively (Table 2).

Table (2): pH values and % of Organic Matter in bed in February and August (2007)

Site	pH		O.M (%)	
	Feb.	Aug.	Feb.	Aug.
RP	7.77	7.62	0.75	0.671
S1	7.90	7.47	0.65	0.671
S2	7.72	7.36	1.65	3.019
S3	7.91	7.95	2.50	0.170
S4	7.93	7.82	0.55	0.503
S5	7.96	7.82	0.44	0.168
S6	7.48	7.80	2.10	0.670
S7	7.72	7.60	4.68	0.340
S8	7.67	7.77	2.33	0.340
S9	7.54	7.65	3.85	3.020
Mean	7.76	7.69	1.95	0.957
Maximum	7.96	7.95	4.68	3.020
Minimum	7.48	7.36	0.44	0.168
Standard Deviation	0.17	0.18	1.45	1.104

As for the results of the heavy metals, they are listed in Table (3). As expected, the heavy metals concentrations in February were not the same as in August. In February, it was (in mg/kg): 20992-150072 of Al, 0.36-0.8 of Cd, 68.4-254 of Cr, 38-333.2 of Cu, 20396-111920 of Fe, 435-4536 of Mn, 32.8-256.4 of Ni, 31.6-162 of Pb and 47.6-298.4 of Zn. While, its concentrations in August have the following range of Al, 128-4064; Cr, 3.2-85.2; Cu, 0.8-14.4; Fe, 958-20263; Mn, 15.6-581.6; Ni, 2-36.4 and Zn, 2.8-88.4. It is worth to mention that, Cd and Pb were not detected in August. The Nile bed sediments in this study were low relative to the concentrations (mean values) of heavy metals in the bed sediments of the Ganga, Neckar, Elbe and Warta Rivers, Table (4).

From these results, it was observed that the high value of heavy metals content in the sediments of the bed surface in February might be related to the high organic matter content. Organic matter played a significant role as a controlling factor to the heavy metals distribution in the bed sediments. These organic matters might be associated with the trace metals and therefore kept as a solution, or it might enhance the association of the trace metals with particle matter by being adsorbed to the particle surface and then combining with the trace metals in the solution phase. Enhanced metal-particulate associations might also be attributed to the metal-organic complexes that are able to adsorb to the surface (Barry, 1982).

During low flow period, the sediments remain undisturbed; consequently most of the trace elements are strongly fixed to the sediment. However, during high flow these anoxic sediments are exposed to an oxic environment the sulfide minerals might be re-oxidized thus releasing the trace elements into the aqueous phase or the transformation into the solid phase to bioavailable forms like exchangeable and carbonate forms (Petersen et al., 1997).

Table (3): Heavy metals concentration (mg/kg) in bed sediments in February and August (2007)

Site Code		RP	S1	S2	S3	S4	S5	S6	S7	S8	S9	Min	Max
Aluminium (Al)*	**Feb**	20.99	26.52	82.25	40.48	41.46	33.57	72.22	118.24	139.64	150.07	20.99	150.07
	Aug	0.13	0.13	0.48	1.24	0.53	0.28	4.06	2.07	3.32	3.38	0.13	4.06
Iron (Fe)*	**Feb**	20.40	37.60	30.81	81.75	63.81	24.49	84.97	96.81	111.45	111.92	20.40	111.92
	Aug	0.96	1.30	1.14	7.38	5.15	5.26	20.26	14.03	7.90	12.80	0.96	20.26
Cadmium (Cd)	**Feb**	0.36	0.40	0.40	0.36	0.36	0.40	0.40	0.40	0.40	0.80	0.36	0.80
	Aug	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Chromium (Cr)	**Feb**	68.4	138.8	153.2	254.0	213.6	78.3	195.2	226.8	170.8	212.8	68.36	254.00
	Aug	3.2	4.8	4.8	29.6	18	9.6	85.2	58.4	35.6	51.6	3.20	85.20
Copper (Cu)	**Feb**	38.04	96.40	92.80	83.20	82.24	56.00	118.80	102.00	333.20	201.20	38.04	333.20
	Aug	0.80	1.20	1.20	4.00	4.00	3.20	10.00	13.60	8.40	14.40	0.80	14.40
Manganese (Mn)	**Feb**	435.2	775.2	971.2	1792.8	1161.6	453.2	1528.8	1679.6	1801.2	4536.4	435.20	4536.40
	Aug	15.6	26.0	18.4	154.0	101.6	34.8	383.6	253.2	194.8	581.6	15.60	581.60
Nickel (Ni)	**Feb**	32.8	44.0	40.0	149.6	52.4	38.0	151.2	166.8	256.4	232.4	32.80	256.40
	Aug	2.00	2.40	3.60	10.00	7.20	22.80	36.40	24.00	10.40	25.20	2.00	36.40
Lead (Pb)	**Feb**	31.6	33.2	44.4	33.2	34.0	35.6	46.0	74.4	67.6	162.0	31.60	162.00
	Aug	3.2	8.4	4	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	3.20	8.40
Zinc (Zn)	**Feb**	47.60	90.40	164.52	158.80	120.52	69.20	162.80	172.40	298.40	296.00	47.60	298.40
	Aug	2.80	4.00	4.40	14.40	14.00	8.00	42.40	47.60	28.40	88.40	2.80	88.40

*Concentration in g/Kg

Table (4): Comparison between the heavy metals in the Nile River and other rivers (mg/kg)

River	Cd	Cr	Cu	Ni	Pb	Zn	Fe	Mn
Warta River (Poland)	14.9	271	170	57.4	236	1396	58411	3771
Elbe River (Germany)	5	460	170	66	170	1100		
Rhine River (Germany)	0.5	40	48	39	70	180		
Neckar River (Germany)	1.8	120	110	44	74	370		
Scheldt River (Belgium)	48		35			230	10400	343
Ganga River (India)	0.1-18.4	76-49937	43-445	21-502	27-549	50-7485	17000-78000	76-49937
Ob River (Russia)	0.06		5.5			20	3100	180
Nile River (Egypt)	nd-0.43	30-171	6-120	14-116	nd-56	25-158	7618-66400	176.6-1514

Boszke et al (2004)

The upper oxic layer of the sediments trace elements may be released to the aqueous phase by mineralization of the freshly deposited organic material (Petersen et al., 1997). Moreover, the formation of new sediment layer that is relatively free from heavy metals is introduced into the main stream by bank erosion and dilutes the heavy metal concentrations by clean sediments (Gaiero et al., 1997).

3.2. Environmental Assessment

General assessment was conducted by comparing the average total heavy metals concentration with the permissible values of different sediment quality objectives (Table 5). The results of this simple comparison revealed that, the Nile bed sediment concentrations upstream barrages are within the permissible limits of standards during August, while the concentrations of Cr, Cu and Ni violate the standard limits during February. However, this comparison with the sediments quality objectives might not be sufficient for assessment of pollution levels in bottom sediments of the area under study. Therefore, another assessment method was applied using certain indices to assess the environmental impacts on sediments. These indices include the Geoaccumulation index (Igeo) and Enrichment factor (EF).

Table (5): Comparison between the heavy metals in the bottom sediment of the Nile River and quality objectives (mg/kg)

Quality Objective	Cd	Zn	Cr	Cu	Ni	Pb
Canadian target[a]	0.6	123	37	36		35
Dutch target[b]	0.8	140	100	36	35	85
German target[c]	1.2	200	100	60	50	100
Agr. Land use[a]	1.4	200	64	63	50	70
Nile River	nd-0.43	25-158	30-171	6-120	14-116	nd-56

[a] Canadian environmental quality guidelines (2002)
[b] Gruiz et al. (1998)
[c] Claussen et al. (1998)

Figures 2 and 3 present the results of Geoaccumulation Index (I_{geo}) along the Nile River upstream the existing barrages during February and August.

Based on Müller scale, Müller (1981), the area located upstream the Delta Barrage (Damietta and Rosetta) and Edfina Barrage was classified to be strongly polluted by metals ($3 < I_{geo} < 4$). However, Damietta Dam was classified to be moderately to strongly polluted ($2 < I_{geo} < 3$) during August. During February, the same area was classified to be moderately polluted by heavy metals. It is worth to mention that the area under study along the Nile is unpolluted by lead and cadmium ($I_{geo} \leq 0$).

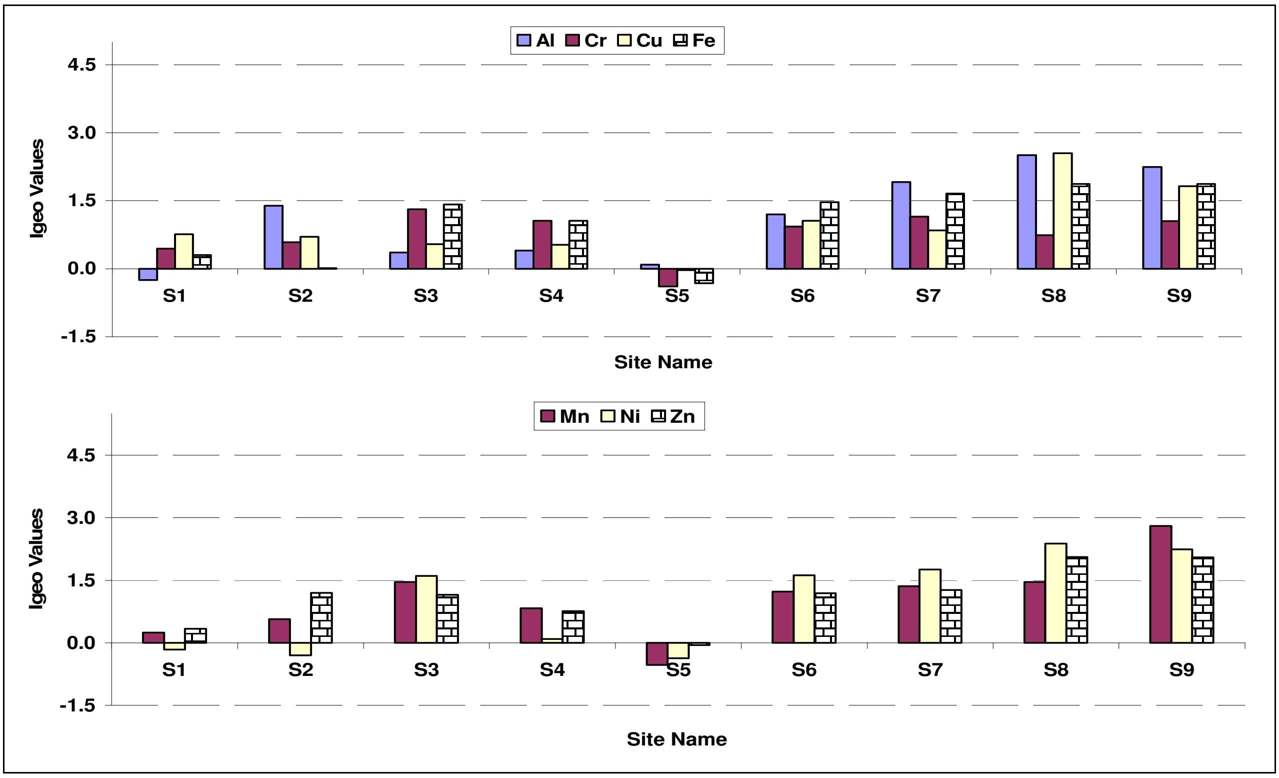

Fig. (2): Geoaccumulation index of heavy metals in the bed sediments at the upstream of the Nile Barrages during February 2007

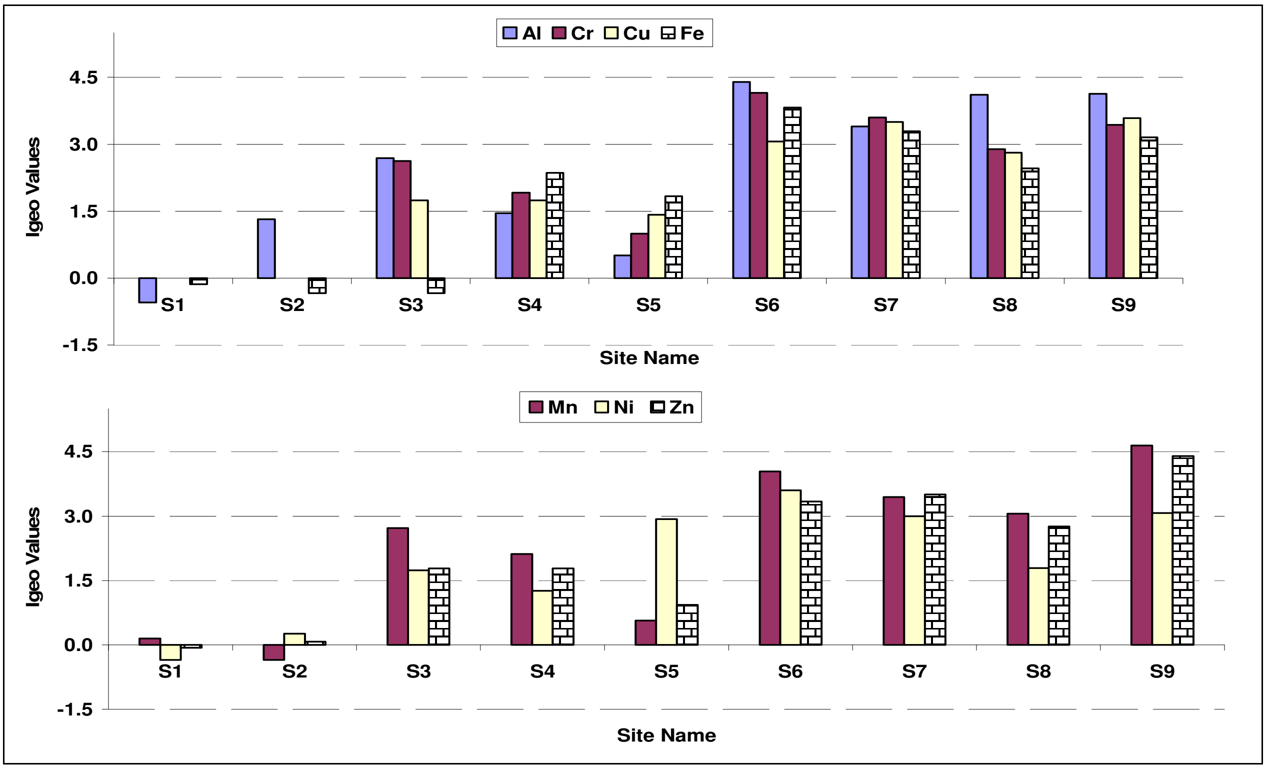

Fig. (3): Geoaccumulation index of heavy metals in the bed sediments at the upstream of the Nile Barrages during August 2007

The values of geoaccumulation index of heavy metals in sediments may be higher during August than the values found during February. It is believed that the transport of the smallest fraction of sediment downstream is due to the river velocity that contributes in the accumulation of heavy metals upstream Delta Barrage (Damietta and Rosetta) and Edfina Barrage.

The calculation of the enrichment factor (EF) for the metals under investigation was computed taking Al content as a reference element. The result of each site is presented on Figure (4). If the concentration of an element is higher than twice the background content, this implies anthropogenic pollution. On the other hand, if the EF value was higher than 2, this indicate contaminated sites (Gonzalez et al., 2000).

Based on this classification the sites upstream the Nile Barrages are not considered to be contaminated by metals. This is because the EF was less than 2, except for the metals Fe, Ni and Mn at the upstream of Esna Barrage during February. Also, the area upstream of Assuit Barrage is contaminated by Fe and Ni, during August (i.e. the EF value is greater than 2).

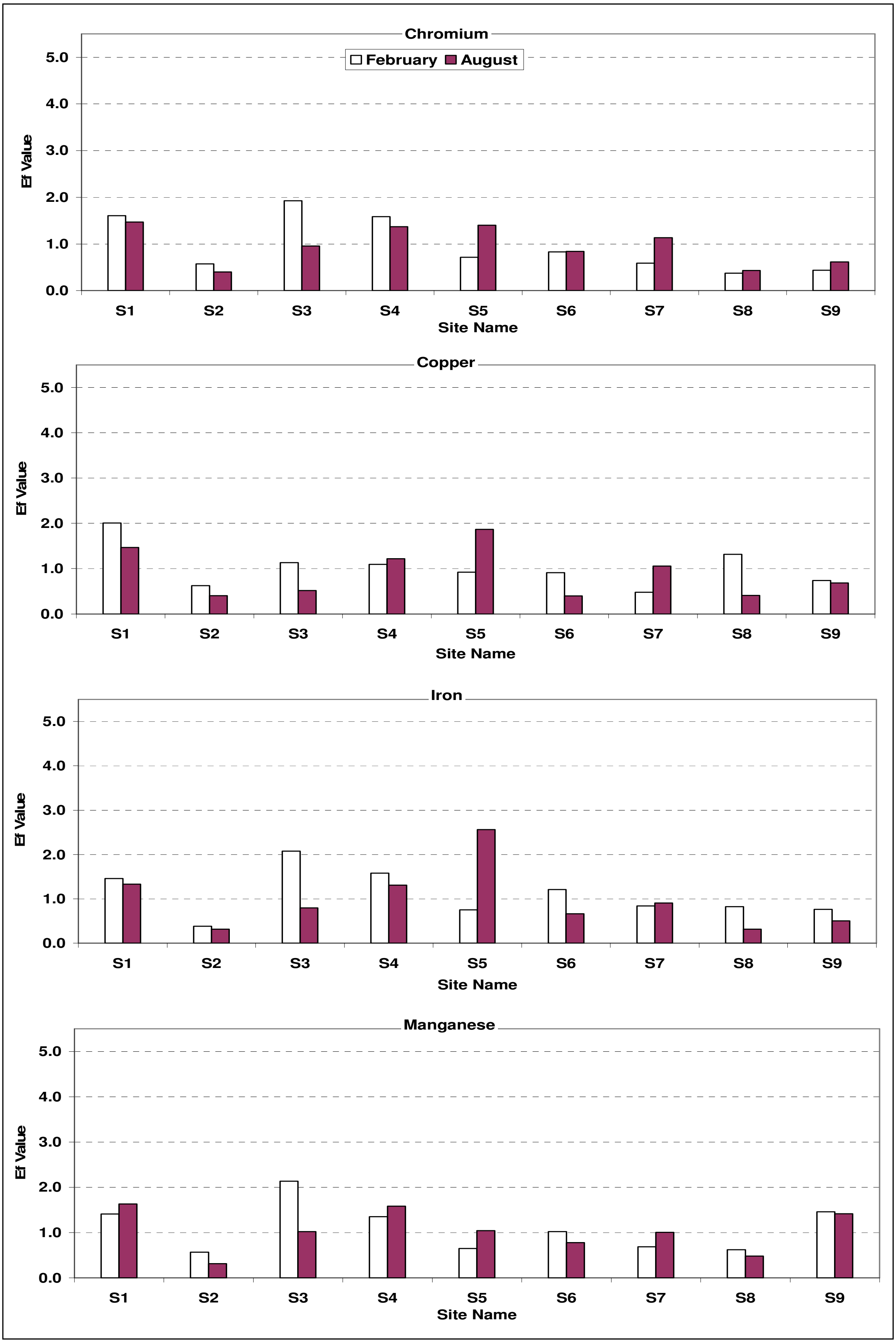

Fig. (4): Enrichment Factor of heavy metals in the bed sediments at the upstream of the Nile Barrages during February/August 2007

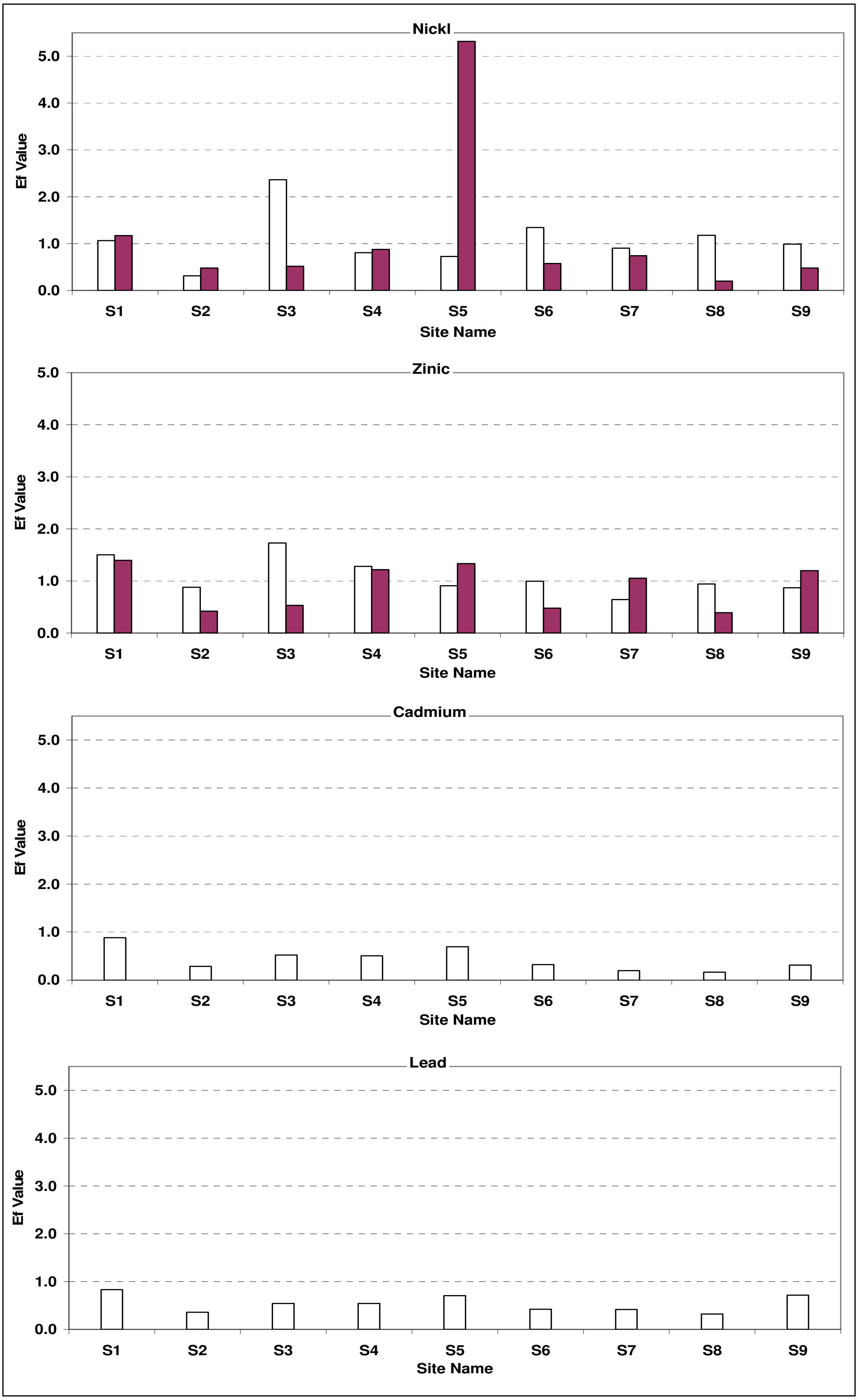

Fig. (4): Continued

3.3. Statistical Analysis for Sediments

The correlation between the analyzed parameters was determined. These analyses showed that, there is a strong correlation between the organic matter and most of the heavy metals during February. Also, it was found that there is a high correlation between most of the heavy metals during the flow conditions of February and August, (Tables 6 and 7).

The strong correlations, between the heavy metals, suggested that they may come from common sources (anthropogenic or natural). A significant correlation between iron and manganese with most metals indicated the occurrence of co-precipitation of these metals with iron manganese oxides. Worthy of attention is also given to the fact that most heavy metals are correlated with organic matter in February but do not show significant correlations in August.

Also an independent two-sample t-test was executed. The results showed that, the p-value is less than 0.05. This indicated that there is a significant difference in the concentrations between high and low flow conditions for heavy metals.

Table (6): Correlation matrix between heavy metals and organic matter in the bed sediments during February 2007

	Al	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn	O.M
Al	1									
Cd	0.620	1								
Cr	0.445	0.214	1							
Cu	0.790*	0.376	0.274	1						
Fe	0.802*	0.458	0.768*	0.730*	1					
Mn	0.757*	0.893*	0.586	0.538	0.775*	1				
Ni	0.847*	0.500	0.586	0.827*	0.952*	0.767*	1			
Pb	0.817*	0.946*	0.345	0.532	0.655*	0.935*	0.689*	1		
Zn	0.927*	0.604	0.564	0.883*	0.865*	0.810*	0.907*	0.757*	1	
O.M	0.794*	0.488	0.656*	0.400	0.785*	0.710*	0.767*	0.698*	0.684*	1

* Significant at 0.05

Table (7) Correlation matrix between heavy metals and organic matter in the bed sediments during August 2007

	Al	Cr	Cu	Fe	Mn	Ni	Zn	O.M
Al	1							
Cr	0.898*	1						
Cu	0.835*	0.852*	1					
Fe	0.867*	0.990*	0.851*	1				
Mn	0.862*	0.825*	0.898*	0.821*	1			
Ni	0.719*	0.854*	0.756*	0.914*	0.731*	1		
Zn	0.790*	0.751*	0.937*	0.751*	0.971*	0.687*	1	
O.M	0.129	-0.027	0.150	-0.056	0.348	-0.023	0.392	1

* Significant at 0.05

4. CONCLUSIONS

Based on the results obtained from this investigation, it was concluded that the organic matter and flow condition are considered the main factors affect the heavy metals distribution along the Nile bed sediments. The detected heavy metals in the Nile bed sediments are within the permissible limits of the different international standards especially during high flow period. Environmental assessment revealed that the area located upstream Delta Barrages (Damietta and Rosetta) and Edfina Barrage is classified to be strongly polluted by heavy metals. The area under study along the Nile River is not contaminated by either lead or cadmium during both flow conditions.

5. RECOMMENDATIONS

From the present investigation, it is recommended to establish speciation to heavy metals to provide relevant information to biological availability or physicochemical reactivity of the bed sediments.

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