

## QUALITY OF RIVER NILE SEDIMENTS FROM IDFO TO CAIRO

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### ABSTRACT

Ten sediment samples from the main channel of River Nile beside four from the banks were collected seasonally from Idfo to Cairo during autumn 2000 to summer 2001.

The present study focuses on the levels of heavy metals (Fe, Mn, Zn, Cu, Ni, Co, Pb and Cd) beside major cations (Na, K, Ca and Mg) in River Nile sediments and the correlations between metal concentrations, sediment particle size, carbonate and organic matter contents. The sediment samples were also analyzed for the exchangeable nutrient groups.

The study revealed that the sand comprised more than 80% of the studied Nile sediment. The exchangeable nutrient showed irregular seasonal trends and the exchangeable phosphate (3.79-18.31  $\mu\text{g/g}$ ) recorded low levels compared with nitrate (2.4-52.28  $\mu\text{g/g}$ ) and ammonia (27.90-595.5  $\mu\text{g/g}$ ).

The Nile sediments are slightly enriched with the major cations and the elevated concentrations of heavy metals are often associated with the industrial pollution. Iron and manganese oxides beside organic matter seem to be the principal carrier phases for most studied heavy metals. Comparison of studied metals to freshwater sediment quality guidelines was cited and discussed.

### INTRODUCTION

Sediment has been described as a ready sink or reservoir of pollutants including heavy metals where they concentrate according to the level of pollution (Becker *et al.*, 2001; Onyari *et al.*, 2003). These sediments play an important role in the environmental studies of rivers as they have long residence time for their interaction with the biotic components of the river's ecosystem (Förstner and Wittmann, 1983) and also play the role of buffer in the control of dissolved metals (Webster *et al.*, 2000; Bordas and Bourg, 2001).

The analysis of heavy metals in the sediments permits detection of pollutants that may be either absent or in low concentrations in the water column (Binning and Baird 2001). The accumulation of metals from the overlying water to the sediment is dependent

on a number of external environmental factors such as pH, Eh, ionic strength, anthropogenic input, the type and concentration of organic and inorganic ligands and the available surface area for adsorption caused by the variation in grain size distribution (Awofolu, *et al.*, 2005).

In natural aquatic systems, the geochemical processes responsible for the exchange of metals at the water-sediment interface are adsorption and precipitation (Salomons and Forstner, 1984). Fe and Mn oxyhydroxides and organic matter either as bulk phases or as coatings of mineral particles are the main adsorbents in sediments (Benjamin and Leckie, 1980; Buffle, 1988; Dzombak and Morel, 1990; Tessier 1992; Bourg and Loch 1995).

The Nile annual flood carries a considerable sediment load estimated to be on the order of 125 million tons (Mancy &

Hafez, 1983). Prior to closure of Aswan High Dam, the alluvial and suspended matters are transported via the Nile down to Egypt and during thousands of years forming the richest agricultural Nile Delta.

After construction the Aswan High Dam, the suspended and alluvial matters are settled down in Lake Nasser leading to loss of nutrients in the sediments (Elewa *et al.*, 1998). Also, water released from the Aswan High Dam is practically silt-free (Saad and Goma, 1994 ) and its suspended solid content is due to phytoplankton (Mancy, 1978). The average amount of suspended matter arrived Gaafra in 1969-1970 did not exceed 2% of that amount delivered in 1960 or 1963 (Hilal and Rashed, 1976).

Nitrogen is considered the key nutrient controlling primary productivity in River Nile (Toullabah, 1996). Both nitrogen and phosphorus are highly particle reactive and when discharged into a waterway, are deposited in bottom sediments incorporated into organic matter (Heggie *et al.*, 2002; Morse *et al.*, 2004). Excess nutrient supplies from atmospheric deposition, agricultural fertilizer runoff, and other anthropogenic sources, can have adverse effects on aquatic ecosystems (Morse *et al.*, 2004) and also control the nitrogen and phosphorus distributions and concentrations in overlying waters and sediments (Boynton *et al.*, 1995; Heggie *et al.*, 2002).

The fluctuation of total phosphorus and organic matter contents in the Nile sediment depends on the variation of the amount of sewage discharged and the texture of sediment (Elewa *et al.*, 1998, Abdel-Satar & Elewa, 2001), where the increase in organic content leads to enriched bottom sediments with the heavy metals and phosphorus. In addition, the rate of accumulation of heavy metals in Nile sediment depends on the physical and chemical conditions of the water body as well as the amount of industrial and sewage effluents flow to the River Nile (Elewa *et al.*, 1997; Elewa and Gohar, 1999; Abdo, 2004).

The objectives of this study are: (1) determining the total heavy metals concentrations and their spatial distribution in stream sediments; (2) investigating the relationship among heavy metals and stream sediment properties; (3) assessment of sediment quality and its relation to urbanization of the River Nile and (4) comparing the concentrations of the heavy metals with freshwater sediment quality guidelines.

## MATERIALS AND METHODS

### Study area

The area of study extends for about 800 Km along the Nile between latitude 25° and 30° in Egypt from Idfo to Cairo during the period from autumn 2000 to summer 2001. The sites of the present investigation from south to north include: Idfo (I), Esna (II), El-Oqsur (III), Qena (IV), Naga Hammadie (V), Souhag (VI), Assiut (VII), El-Menia (VIII), Beni-Suef (IX), El-Hawamdia (X), Fig 1.

### Methods of analysis

Ten sediment samples from these sites were taken seasonally from the main channel of the River Nile beside 4 samples from the banks include I (in front of the Egyptian ferro-alloy Company), II & III (in front of Touristic Galleon parking) and X (in front of the Sugar and Integrated industries Company). These were collected superficially using Ekman dredge and kept frozen at -18 °C until analyzed. pH of the bottom water at the same sites was measured by Orion Research Ion Analyzer 399A pH meter.

For total heavy metals, sediment samples were allowed to defrost, then air-dried in a circulating oven at 30°C and sieved mechanically using a 2 mm sieve. A total digestion for 1 gram sieved sediment according to Jackwerth and Würfels (1994) method to complete dissolve all elements present in stream sediments. The elements of concern are: Na, K, Ca, Mg, Fe, Mn, Zn, Cu, Co, Ni, Pb and Cd. The solutions were directly analyzed for total Na, K, Ca, Mg, Fe,

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Mn, Zn, Co and Ni using atomic absorption spectrophotometer model (Perkin Elmer 3110 USA), while total Cu, Pb and Cd using atomic absorption with graphite atomizer HGA-600.

The sediment samples were also analyzed for a number of chemical parameters: the exchangeable nutrient groups, organic matter, and carbonate content. The organic matter content was determined by oxidation with  $K_2Cr_2O_7$  in acidic media (Jackson *et al.*, 1984), the carbonate content was determined as reported in Vogel (1982). The concentrations of exchangeable ammonia, nitrite and nitrate were measured using the KCl extraction and quantitated directly by indophenol blue, Griess-Hosvay and

hydrazine- $CuSO_4$  reduction methods, respectively following American Society of Agronomy (1982). Available phosphorus is extracted by  $NaHCO_3$  and colorimetrically determined as orthophosphate by molybdenum blue method (Murphy and Riley, 1962).

The sediment particle analysis was done following Parker method (1983). The samples were oven-dried at  $60^\circ C$  for 48 h, and a 30 g portion of sediment from each site was washed and re-weighed after drying. The dry samples were put on the topmost sieve and sieved by machine for 8 min. The fraction of each sieve was weighed, and the median grain size, mud composition, and all other sand fractions were determined.

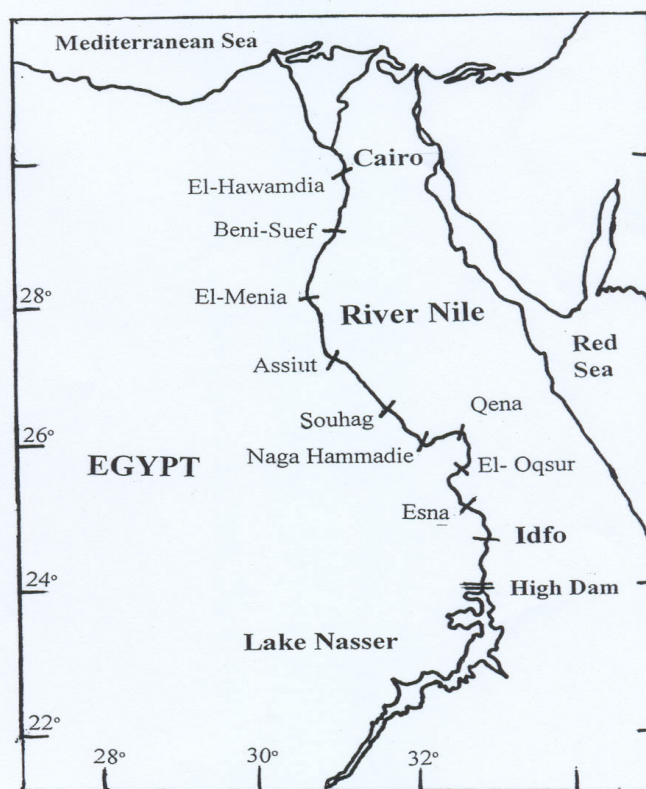


Fig. (1): Map showing the sampling sites along the River Nile

**RESULTS AND DISCUSSION**

**Nature of stream sediments**

Grain size and mineralogy of sediments are significant factors controlling mobility and dispersion of heavy metals in a river system (Salomons, 1980). The average grain size distributions for the sediment samples collected from River Nile are summarized in Table (1). Grain size analysis of the River Nile upstream of the Aswan High Dam have shown that stream sediments are mainly composed of sand. Sand comprised more than 80 % of the studied Nile sediment. Sand and finer material also was found further upstream at the banks. Site II (east) sample had high percent of mud (16.02 %) compared to others sites (0.001-5.20 %). The field notes

indicate bank samples contained plant fragments or wood chips.

**pH of bottom water**

pH values were ranged between 7.1-9.0, Fig. 2. The increase in pH promotes the precipitation of metals, which subsequently settle to the bed River and ultimately result in reduced water column concentrations and perhaps increased concentrations of metals in sediments (Forstner and Wittmann 1983).

The decrease in pH during summer seasons (7.10-7.69) may be attributed to the decomposition of descending plankton and organic matter, leading to the release of hydrogen sulphide and the formation of organic acids and other breakdown products (Saad, 1980; Elewa and Ghallab 2000).

**Table (1): Summary of sieve test results for sediment samples collected from the River Nile**

<i>Site</i>	<i>Gravel %</i>	<i>Very coarse sand %</i>	<i>Coarse sand %</i>	<i>Medium sand %</i>	<i>Fine sand %</i>	<i>Very fine sand %</i>	<i>Mud %</i>
<b>I</b>	0.11	0.08	0.37	31.05	66.60	1.72	0.07
<b>I (east)</b>	0.98	0.79	0.41	1.99	50.39	38.34	7.10
<b>II</b>	4.98	1.11	2.16	27.71	35.39	23.77	4.88
<b>II (east)</b>	0.14	1.23	1.73	6.40	30.21	44.26	16.02
<b>III</b>	0.50	1.27	3.93	47.47	46.50	0.30	0.03
<b>III (east)</b>	2.70	12.40	19.75	47.08	16.47	1.28	0.31
<b>IV</b>	1.06	3.40	5.77	51.16	38.03	0.56	0.03
<b>V</b>	0.46	0.08	0.05	0.27	89.33	4.62	5.20
<b>VI</b>	14.26	6.31	4.05	5.05	61.78	7.48	1.08
<b>VII</b>	0.39	0.28	2.93	88.10	7.46	0.77	0.06
<b>VIII</b>	0.42	3.02	6.17	58.81	29.71	1.51	0.37
<b>IX</b>	6.59	37.56	23.44	30.83	1.56	0.02	0.001
<b>X</b>	14.26	6.31	4.05	5.05	61.78	7.48	1.08
<b>X (east)</b>	0.09	0.84	1.50	9.08	71.72	12.92	3.85

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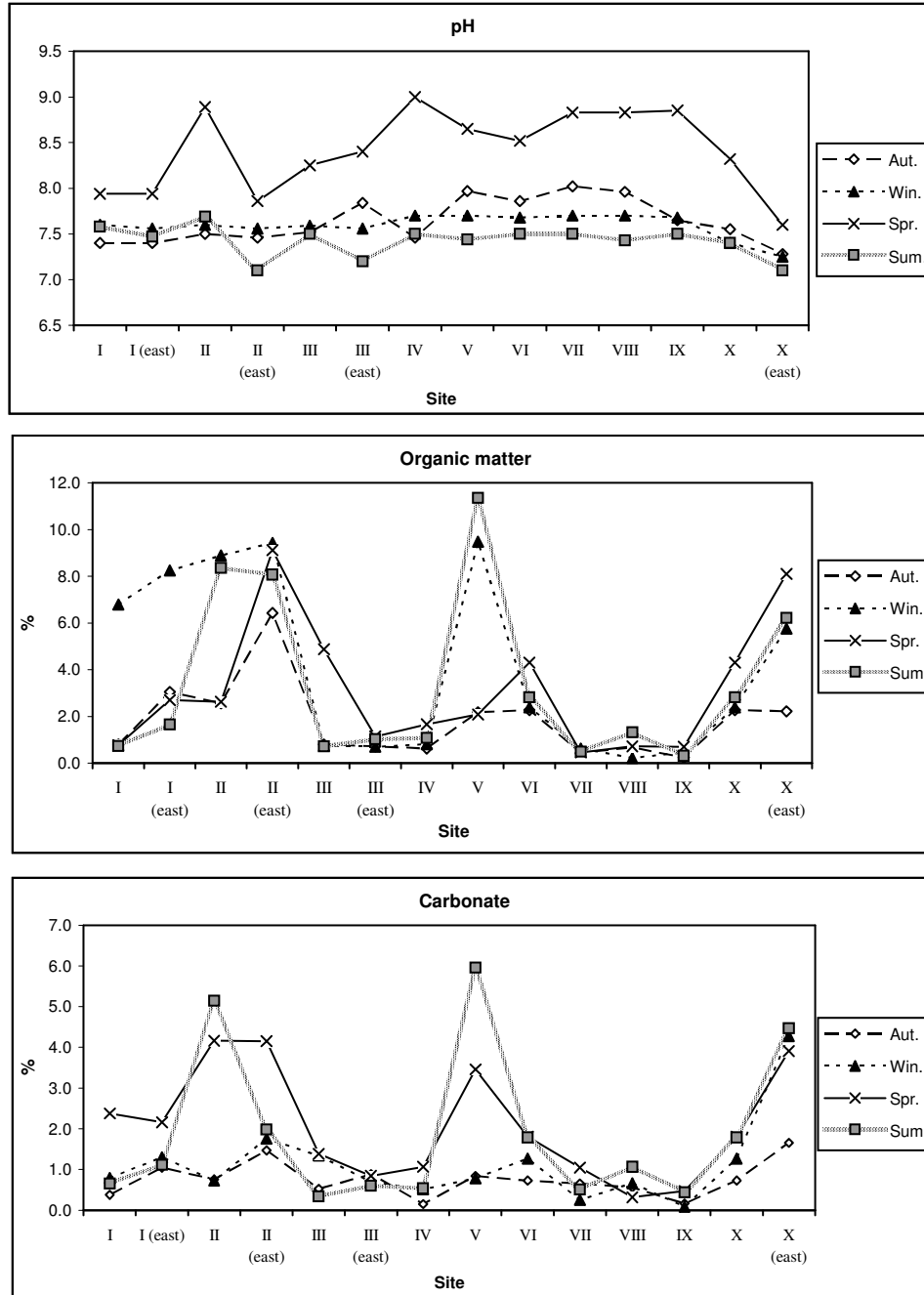


Fig. (2): Variations in pH (bottom water), organic matter and carbonate contents (bottom sediment) of River Nile

### Organic matter and carbonate contents

The organic matter (OM) data in the Nile sediment (Fig. 2) are ranged from 0.23 to 11.35 %. The distribution of organic content in the Nile sediments depends principally upon particle composition of the sediments and the allochthonous organic load entering into the Nile with sewage and industrial wastes (Elewa *et al.* 1997; Abdo 2004). Where, sites I (east), II (east, middle), V and X (east) containing high percentage of mud, showed the highest values of OM, while site IX containing low percentage has the minimum value of OM

Organic matter in sediment tends to decrease the availability of metals to sediment dwelling organisms because of the formation of complexes between metals and organic matter (Black and Williams 2001; Camusso *et al.*, 2002). In general, the stability of natural humic complexes follows the Irving-Williams order for complexation of divalent metals:  $Hg > Cu > Pb > Zn > Cd > Fe$  (Compbell *et al.*, 1988). This is confirmed by the higher positive correlation between OM and Cu than other metals, Table (5), where the immobilization of more than 90 % Cu by surface adsorption and complexation by organic matter (Bertin and Bourg, 1995; Yu *et al.*, 2000)

Carbonate content decreases slightly during autumn and winter and ranged between 0.085 to 5.96 % with high increase at sites II (middle), V and X (east) in summer, Fig. 2. These high values of carbonate are due to the enrichment of sediments by mollusca and partly by calcareous fragments as site II (middle) and increase the percent of mud in other sites.

The observed high positive correlation between OM and carbonate, Table 5, is mainly attributed to the fermentation processes, which may occur to sinking dead materials yielding organic matter, and releasing the calcium carbonate to surface sediment from death calcareous shells (Goltermam, 1975).

Carbonate possessed positive correlations with each of Fe, Mn, Zn, Cu, Ni,

Co and Pb, Table 5. Therefore, these metals are probably present in the form of carbonate in the stream sediments.

### Exchangeable nutrient concentrations

Internal nutrient loading is important to consider when determining the trophic condition of a water body, as nutrient release from sediments can potentially supply most of the nutrient requirements of algae (Liikanen *et al.*, 2002 Johnston and Minnaard 2003).

The phosphate ion is a highly particle-reactive molecule and thus the sorption properties of sediment are crucial for P-retention capacity. Generally, aerobic conditions are considered to promote phosphorus sorption and anoxic conditions to favour phosphorus release (Khoshmanesh *et al.*, 2002).

Available phosphate showed irregular seasonal trends, their values were fluctuated at different sites from the lowest value (3.79  $\mu\text{g/g}$ ) at site II (middle) in summer to the highest (18.31  $\mu\text{g/g}$ ) at site VI in winter, Fig. 3.

The phosphate levels released from the sediment of all sites during summer season (high water discharge) showing the minimum values, this indicates the decrease in phosphate content in Nile sediment due to the increase of mobilization of phosphorus from sediment to Nile water by increase in water temperature and water currents. However, the main physical factors enhancing the exchange of phosphorus between sediment and water are temperature and water turbulence (Bostrom *et al.*, 1988).

Phosphate is known to bind sediment more closely than other nutrients and this may explain the lack of exchangeable phosphate (3.79-18.31  $\mu\text{g/g}$ ) recorded compared to the nitrate (2.4-52.28  $\mu\text{g/g}$ ) and ammonia (27.90-595.5  $\mu\text{g/g}$ ), Fig. 3. In addition, the sorption reactions of phosphorus caused inorganic particles are enhanced as a function of decreasing sediment grain size. Silicates and carbonates in larger particles such as sand (Nile stream sediments are mainly composed of sand) adsorb phosphorus

poorly and have a high affinity to adsorb cations but not anions such as  $\text{PO}_4^{3-}$  (Bostrom *et al.*, 1988; Lehtoranta *et al.*, 1997). This may declare the increase in exchangeable ammonia level than the other forms of nitrogen in Nile sediment, Fig.3.

The nitrogen cycle in waters is more complex than the phosphorus cycle. Organic matter both particulate and dissolved is broken down by bacteria and fungi to ammonium ( $\text{NH}_4^+$ ). When the sediments are aerobic, the ammonium is oxidized to nitrite ( $\text{NO}_2^-$ ) and then to nitrate ( $\text{NO}_3^-$ ), through the nitrification process (Boulton and Brock, 1999; Morse *et al.*, 2004).

Previous studies performed in a variety of trophic status water bodies have shown greater amounts of nitrate ( $\text{NO}_3^-$ ), and ammonium ( $\text{NH}_4^+$ ) to be released from sediments under anaerobic conditions compared to those of aerobic (Liikanen *et al.*, 2002, Johnston and Minnaard, 2003).

The sediment is very rich in nitrogenous compounds, while the sandy sediments are nutrient poor (Boey, 1997). The dominant species of nitrogen in the Nile sediment is ammonia. Ammonia-nitrogen results were varied between the lowest value 23.10  $\mu\text{g/g}$  recorded at site VII in autumn to highest 493.50  $\mu\text{g/g}$  recorded at site X in winter. Ammonia levels showed high values at sites I (east), II (east, middle), V, VI and X than the others. Some of these differences were probably due to the changes in the percentage of the mud fraction in Nile sediment. This was achieved by the positive correlation between ammonia and mud percent ( $r=0.81$ ). Ammonia itself is a non-persistent and non-cumulative toxic substance, thus the high levels of ammonia released by the sediment are not a great problem at present. However, if the DO % is low and the pH level is high, then such high levels of ammonia may become a problem, given that ammonia toxicity increases under such conditions (Johnston and Minnaard, 2003).

The exchangeable  $\text{NO}_3^-$ -N concentrations are mostly higher (2.40-52.28  $\mu\text{g/g}$ ) than  $\text{NO}_2^-$ -N values (0.17-1.06  $\mu\text{g/g}$ ) and the two showed random distribution along different sites and seasons, Fig. 3. This declare the oxidized conditions of Nile sediment, where some organic nitrogen is eventually oxidized to nitrate which can be either released to overlying waters or denitrified in sediments. Boynton *et al.*, (1997) reported that the influence of dissolved oxygen conditions on sediment-water exchanges of nutrients is strong; affecting both nitrogen and phosphorus. Under low dissolved oxygen conditions, the transformation of organic nitrogen to more oxidized forms than ammonium ceases and ammonium becomes the dominant form of nitrogen released from sediments (Takita and Edwards 2001).

The present study revealed that positive correlation is obtained between exchangeable ammonia and organic matter ( $r=0.55$ ) as well as carbonate ( $r=0.50$ ), where the decomposition of deposited organic material releases inorganic C, N compounds which may be returned to the water column (Morse *et al.*, 2004).

#### Major cations

The Nile sediments are slightly enriched in Na, K, Ca and Mg where the order of abundance was  $\text{Na} > \text{K} > \text{Ca} > \text{Mg}$ . The values of Na were ranged from 10.75 to 41.72 mg/g, Table 2. Relatively low values were estimated at most sites in summer but without clear seasonal trends. The highest concentrations were exclusively registered for site II (east) in spring in front of Touristic Galleon parking and the lowest in winter season at site IX. Potassium concentrations fluctuated between 4.20 to 13.29 mg/g with high increase at site X (east) during most seasons, which reflects the effect of effluents discharged from Sugar and Integrated industries Company, Table 2. The minimum values were recorded for sites VIII and IX in winter. The two elements fulfilled positive relationship, Table (5).

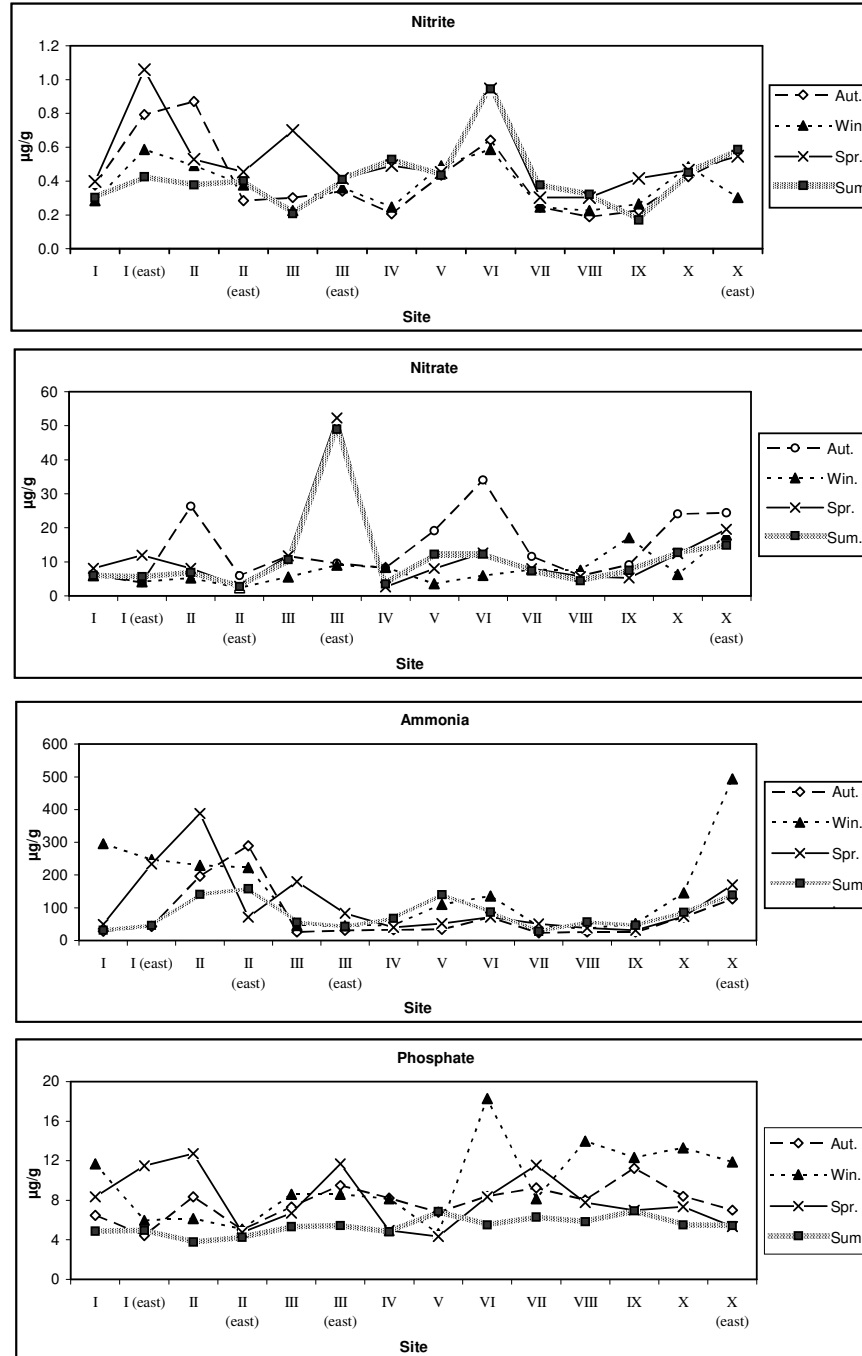


Fig. (3): Variations in exchangeable nutrients concentration of the River Nile sediment



Ca and Mg occur naturally in sediment and are the most common ions in freshwater and a major contributor to water hardness (USEPA, 1987). Ca and Mg levels (0.23-5.20 and 0.44-0.87 mg/g respectively), were essentially constant throughout the river sediment and exhibited slight seasonal differences at most sites, Table 2. The values during hot seasons showed slight increase than cold seasons. They were relatively constant downstream from site II to IX, while sites I (east) gave minimum concentrations due to competition between heavy minerals and metals discharged from the Egyptian ferro-alloy Company with hardness ions. In addition, X (east) showed the maximum probably due to the effluent discharges from Sugar and Integrated industries Company.

The decreases in Ca and Mg during cold seasons are mainly due to the release of CO<sub>2</sub> from sediments because of oxidation of organic matter (Elewa *et al.*, 1998). Consequently, a decrease in pH leads to the dissolution of Ca and Mg carbonate from sediments (Saad, 1987). While, the increase in their concentrations are mainly attributed to the precipitation of CaCO<sub>3</sub> and MgCO<sub>3</sub> by the ability of phytoplankton to extract CO<sub>2</sub> from water and raise the pH in spring season.

The positive correlation between carbonate with Ca and Mg, Table 5, indicated the association of both elements with carbonate in the mode of precipitation in Nile sediments. The weakness of correlation between Ca and Mg with heavy metals, Table (5), explained that in highly buffered systems, hardness ions may inhibit heavy metals sorption to the solid phase either through competition with heavy metals for particulate binding sites or through their ability to compress the electrical double layer at the solid surface-solution interface (O'Shea and Mancy, 1978).

#### **Total metal concentrations**

Heavy metal concentrations in the water column can be relatively low, but the concentrations in the sediment may be

elevated. Low-level discharges of a contaminant may meet the water quality criteria, but long-term partitioning to the sediments could result in the accumulation of high loads of pollutants (Binning and Baird, 2001). Therefore, the monitoring of the sediment with the determination of heavy metals is fundamental to the realization of toxic pollutants in the river sediment (Ho and Hui, 2001; Black and Williams 2001).

Results of metal analysis of stream Nile sediments from Idfo to Cairo are presented in Tables 3 and 4. No consistent trends in sediment metal concentrations were observed going downstream. Iron recorded high values at all sites in the Nile sediment, indicating that this metal is naturally high in the sediments. It is varied between 11.49 to 15.41 mg/g and their levels were essentially constant throughout the river sediment. These results were in agreement with those obtained by Elewa *et al.*, (1998), Elewa and Gohar (1999), Abdel-Satar and Elewa (2001) and Abdo (2004). They recorded that the total iron concentrations were in the range 6.67-25.74, 6.53-34.61, 5.34-20.63 and 9.85-16.16 mg/g, respectively in the Nile sediments. No guideline is set for iron, which is generally not toxic to biota (Cousins *et al.*, 2002).

Manganese concentrations showed slight variability among sites without clear seasonal trends, ranging between a minimum 0.094 mg/g at site VIII and a maximum of 2.425 mg/g at the east of site I in winter. Concentrations minima usually occurred at sites III, IV, VII, VIII, IX and X in different seasons reflects the decrease in mud percent at these sites. Only three samples from sites I (in front of the Egyptian ferro-alloy Company) and X (in front of the Sugar and Integrated industries Company) along different seasons contained concentrations that slightly exceeded the severe effect level (1.1 mg/g) cited by Persaud *et al.*, (1993) for the protection of freshwater sediments in Ontario.

Zinc is a relatively abundant "trace" metal, found at varying concentrations in

nearly all uncontaminated aquatic ecosystems. It will predominantly bind to suspended material before finally accumulating in the sediment (Alloway 1990; Bryan and Langston 1992). Zn concentrations in the stream sediments displayed a wide range (102.20-261.35  $\mu\text{g/g}$ ) without consistent seasonal trends. The highest value was recorded at site I and the lowest at site X in winter season. It is showed high positive correlation with each of OM, carbonate, Fe and Mn concentrations, Table 5, suggesting that the importance of OM,  $\text{CO}_3^{2-}$ , Fe and Mn oxides in the accumulation of heavy metal to the sediment under oxic conditions (Abdel-Satar & Elewa 2001; Abdo, 2004).

The concentrations of total Cu, Ni, Co and Pb were displayed a wide range varied between 1.93-62.60, 10.00-70.67, 15.33-69.37 and 2.20-52.22  $\mu\text{g/g}$ , respectively clearly peaking for Cu, Co and Pb at sites I in winter and II (east), V and X (east) during most seasons. In addition, sites VII, VIII and IX showed the lowest levels of these metals. The wide ranges of metal concentrations may be attributed to variations in mud percent and increase in heavy metals rich urban effluents draining into river. The decrease in Cu, Ni and Pb during cold seasons, at most sites may be attributed to the decrease in sorption of metals to solid phase with the decrease in water temperature, this in harmony to that reported by Warren and Zimmerman (1994) for Don River.

Cd concentrations fluctuated markedly in the stretches of the river, ranging between 0.58  $\mu\text{g/g}$  at Beni-Suef with very low mud percent (0.001%) and a maximum of 12.61  $\mu\text{g/g}$  at the east of El-Hawamdia site. The high increase in Cd level at site X (El-Hawamdia) reflects the discharge of Sugar and Integrated industries Company. The

presence of these metals in the aquatic ecosystem has far-reaching implications directly to the biota and indirectly to man (Camusso *et al.*, 2002).

The weakness of correlation between Cd and OM, Table 5, may be attributed to the low stability constant of cadmium humic complexes, consequently, cadmium is less likely to form stable organic complexes (Compbell *et al.*, 1988). In addition, the correlation of Cd, with most studied metals was not significant, Table 5.

Generally, heavy metals concentrations in Nile sediment showed a general increase with increasing in fine silt and clay fractions, which are good enough to accumulate higher quantities of heavy metals in sediments (Yu *et al.*, 2000; Ansari *et al.*, 2000; Singh, *et al.*, 2002; Cousins *et al.*, 2002). This is achieved by the positive correlation between mud percent with each of Fe, Mn, Zn, Cu, Ni and Co ( $r=0.56, 0.83, 0.79, 0.89, 0.85$  and  $0.69$ , respectively).

More significant correlation coefficients among heavy metals (Fe, Mn, Zn, Cu, Ni, Co and Pb) were deduced, Table 5. This indicates either their common sink in the stream sediments or their common urban origin. Based on the observed associations, Table 5, Fe and Mn beside OM seem to be the principal carrier phases for some heavy metals as Zn, Cu, Ni, Co and Pb in oxic Nile sediment because they have a large sorptive capacity (Abdel-Satar and Elewa 2001; Abdo, 2004). Furthermore, they appear as coatings on the particles and occlude the other mineral (Bertin and Bourg 1995 Schlomer, 2001). This is confirmed by the significant positive correlation between Fe, Mn and OM with each of Zn, Cu, Ni, Co and Pb, Table 5.

Table (2): Seasonal variations of major cations concentrations (mg/g) in the Nile sediment

Site	Autumn					Winter					Spring					Summer				
	Na	K	Ca	Mg	Mg	Na	K	Ca	Mg	Mg	Na	K	Ca	Mg	Mg	Na	K	Ca	Mg	
I	31.43	9.770	0.225	0.554	30.60	10.055	0.501	0.579	27.07	9.869	1.026	0.641	10.059	4.009	0.795	16.54	10.059	4.009	0.795	
I (east)	26.47	9.006	3.460	0.589	27.71	10.110	3.543	0.655	23.57	8.905	3.615	0.660	10.185	3.714	0.674	22.37	10.185	3.714	0.674	
II	30.19	9.998	2.908	0.657	24.81	8.594	3.717	0.633	26.05	10.039	3.524	0.652	11.386	2.681	0.698	21.09	11.386	2.681	0.698	
II (east)	27.29	9.006	3.235	0.592	20.68	9.281	3.811	0.655	41.72	8.730	3.364	0.668	8.954	3.265	0.641	26.37	8.954	3.265	0.641	
III	23.57	9.075	2.869	0.575	18.20	8.388	3.006	0.560	32.67	9.690	3.572	0.669	9.428	3.578	0.748	15.30	9.428	3.578	0.748	
III (east)	23.98	7.494	3.025	0.559	25.70	8.010	3.006	0.554	23.98	9.603	3.458	0.652	21.92	3.363	0.666	19.44	10.640	4.611	0.864	
IV	21.92	8.938	2.743	0.551	24.40	8.456	3.345	0.599	24.81	9.254	3.515	0.660	10.640	4.611	0.864	19.44	10.640	4.611	0.864	
V	33.08	11.750	2.825	0.621	23.16	9.144	3.284	0.637	20.26	9.167	3.269	0.638	16.95	10.000	5.197	0.853	10.000	5.197	0.853	
VI	36.32	13.294	3.246	0.578	23.57	8.525	3.382	0.605	23.57	10.001	3.510	0.674	23.57	10.001	4.360	0.857	10.001	4.360	0.857	
VII	20.26	6.394	1.767	0.506	17.78	6.394	2.866	0.561	14.89	6.548	2.568	0.584	14.06	8.381	3.540	0.750	8.381	3.540	0.750	
VIII	20.68	7.563	2.763	0.551	21.23	4.200	1.365	0.439	15.30	5.500	2.629	0.594	12.82	8.381	3.845	0.729	12.82	8.381	3.845	
IX	18.61	5.156	1.804	0.495	10.75	4.263	1.901	0.487	21.92	8.294	2.848	0.594	11.58	6.518	2.873	0.713	11.58	6.518	2.873	
X	21.72	8.938	1.767	0.578	24.38	8.456	2.866	0.605	24.12	9.254	2.568	0.674	19.36	10.640	3.540	0.857	19.36	10.640	3.540	
X (east)	26.47	9.263	1.805	0.649	23.57	10.152	3.896	0.631	19.44	10.991	4.293	0.838	21.50	11.106	4.857	0.870	21.50	11.106	4.857	

Table (3): Seasonal variations of iron, manganese (mg/g), zinc and copper (µg/g) in the Nile sediment

Site	Autumn					Winter					Spring					Summer				
	Fe	Mn	Zn	Cu	Cu	Fe	Mn	Zn	Cu	Cu	Fe	Mn	Zn	Cu	Cu	Fe	Mn	Zn	Cu	
I	14.13	0.434	162.23	12.63	49.14	14.43	1.140	261.35	49.14	14.00	0.201	120.68	5.62	14.40	0.299	125.91	7.73	14.40	0.299	
I (east)	14.13	1.104	175.52	30.45	34.85	14.18	2.425	171.08	34.85	14.09	0.913	155.92	31.38	14.10	1.065	159.84	30.82	14.10	1.065	
II	14.04	0.472	139.63	13.98	42.47	14.12	1.045	187.78	42.47	14.00	0.807	155.80	20.92	15.25	0.688	252.11	47.76	15.25	0.688	
II (east)	14.14	1.047	196.70	39.32	41.72	14.19	1.058	192.37	41.72	14.22	0.775	199.05	62.60	14.26	0.825	198.61	58.64	14.26	0.825	
III	13.34	0.227	111.38	4.32	7.25	13.59	0.387	116.72	7.25	14.14	0.984	180.38	27.38	14.03	0.238	120.58	7.73	14.03	0.238	
III (east)	13.43	0.296	113.25	4.00	6.00	13.10	0.289	113.20	6.00	14.00	0.743	149.33	12.20	14.02	0.651	146.56	11.00	14.02	0.651	
IV	13.48	0.285	114.77	4.08	6.97	13.69	0.340	119.50	6.97	14.04	0.591	150.52	17.22	15.31	0.368	149.44	15.93	15.31	0.368	
V	14.09	0.491	160.58	14.25	52.45	14.18	1.026	199.47	52.45	13.64	0.348	120.32	19.10	15.39	1.017	158.27	35.49	15.39	1.017	
VI	14.02	0.620	158.37	20.38	18.20	14.11	0.737	151.02	18.20	14.13	0.816	176.58	32.37	15.41	0.549	170.33	26.00	15.41	0.549	
VII	12.52	0.099	102.32	1.99	4.27	13.44	0.239	113.25	4.27	12.95	0.136	114.02	4.48	14.15	0.248	119.98	10.40	14.15	0.248	
VIII	13.01	0.167	106.05	2.93	2.09	11.49	0.094	103.42	2.09	13.79	0.393	128.40	9.40	13.15	0.124	110.91	3.89	13.15	0.124	
IX	12.63	0.189	102.58	1.93	2.09	13.06	0.203	104.15	2.09	13.31	0.163	113.73	3.88	13.08	0.110	115.93	2.22	13.08	0.110	
X	13.01	0.238	122.60	8.05	13.21	12.00	0.198	102.20	13.21	13.35	0.218	187.00	15.23	13.96	0.311	181.20	12.01	13.96	0.311	
X (east)	14.12	0.425	156.86	15.54	49.67	14.16	1.054	183.13	49.67	15.36	0.696	199.44	57.56	15.36	1.185	200.89	48.11	15.36	1.185	

Table (4): Seasonal variations of nickel, cobalt, lead and cadmium concentrations (µg/g) in the Nile sediment

Site	Autumn				Winter				Spring				Summer			
	Ni	Co	Pb	Cd	Ni	Co	Pb	Cd	Ni	Co	Pb	Cd	Ni	Co	Pb	Cd
I	11.65	43.75	10.00	2.70	66.91	67.89	41.88	8.53	12.67	21.45	11.39	3.98	24.78	31.13	12.89	2.40
I (east)	67.68	50.50	11.83	1.62	53.10	54.37	20.78	3.05	51.57	45.90	26.67	1.60	52.69	49.84	23.34	1.61
II	25.14	53.40	45.61	7.70	54.73	61.07	29.17	4.03	43.80	47.32	27.17	2.25	58.62	57.53	15.11	5.00
II (east)	58.78	55.32	18.33	1.95	53.40	47.07	36.33	3.83	70.67	69.37	42.17	3.27	54.63	60.21	35.63	2.98
III	10.00	34.52	6.50	3.38	19.02	27.95	7.83	2.95	44.15	54.95	30.00	2.62	16.49	19.89	9.89	1.40
III (east)	10.90	35.58	11.33	1.83	10.00	34.23	11.00	1.78	35.05	34.08	22.17	3.42	28.33	33.96	20.69	3.10
IV	10.00	32.35	4.33	3.70	12.37	42.10	6.50	2.55	51.40	43.22	23.50	1.90	52.13	43.27	21.33	1.62
V	35.84	58.86	33.33	7.25	54.03	66.97	25.83	3.90	27.13	23.28	13.83	1.45	45.62	56.40	34.22	3.84
VI	26.95	49.42	15.33	3.88	29.17	45.30	8.82	4.48	55.03	58.87	35.83	3.30	59.20	53.22	22.67	3.60
VII	10.00	28.35	3.83	1.97	10.00	32.47	4.60	2.30	18.13	20.20	11.50	1.37	22.27	23.89	12.22	0.71
VIII	14.78	28.57	8.83	2.70	15.13	16.02	2.20	2.33	27.95	24.62	11.00	0.92	20.38	20.02	6.56	1.29
IX	10.00	23.77	4.83	2.38	10.00	20.55	2.50	1.58	17.30	21.83	11.50	0.58	11.78	15.33	5.89	4.00
X	16.95	32.15	33.33	3.87	29.17	42.12	20.83	2.55	52.03	43.67	23.83	1.87	54.20	43.45	34.22	1.64
X (east)	21.58	51.51	44.56	12.61	60.33	62.97	23.50	2.97	66.44	63.78	36.44	2.87	66.02	67.42	52.22	2.89

Table (5): Correlation matrix of sediment quality data

	OM	CO <sub>3</sub> <sup>2-</sup>	Fe	Mn	Zn	Cu	Ni	Co	Pb	Cd	Na	K	Ca	Mg
OM	1.00													
CO <sub>3</sub> <sup>2-</sup>	0.62	1.00												
Fe	0.55	0.52	1.00											
Mn	0.71	0.37	0.54	1.00										
Zn	0.79	0.50	0.69	0.67	1.00									
Cu	0.90	0.62	0.63	0.73	0.87	1.00								
Ni	0.76	0.56	0.66	0.71	0.87	0.87	1.00							
Co	0.78	0.50	0.65	0.71	0.85	0.86	0.81	1.00						
Pb	0.64	0.48	0.54	0.50	0.67	0.67	0.68	0.76	1.00					
Cd	0.24	0.09	0.22	0.16	0.35	0.20	0.09	0.42	0.50	1.00				
Na	0.31	0.14	0.18	0.39	0.44	0.40	0.34	0.61	0.44	0.39	1.00			
K	0.40	0.42	0.71	0.44	0.59	0.47	0.53	0.63	0.56	0.31	0.48	1.00		
Ca	0.35	0.49	0.53	0.36	0.18	0.35	0.47	0.32	0.28	-0.27	-0.15	0.39	1.00	
Mg	0.34	0.50	0.73	0.22	0.37	0.35	0.51	0.33	0.48	-0.01	-0.16	0.57	0.70	1.00

**Comparison of metals to sediment quality guidelines**

Various investigators have developed sediment quality guidelines to assess possible adverse biological effects from heavy metals (e.g., Persaud *et al.*, 1993; MacDonald *et al.*, 2000).

The USEPA has established sediment-quality guidelines in the form of “level-of-concern concentrations” for several heavy metals (U.S. Environmental Protection Agency, 1997). These concentrations were derived from biological effects correlations made on the basis of paired on site and laboratory data to relate incidence of adverse biological effects to dry-weight sediment concentrations. In addition, Salomons & Forstner (1984) and U.S. Public Health Service (USPHS) (1997) cited background concentrations of metal found in freshwater sediments, Table 6.

The heavy metals concentrations from the Nile sediments did not exceed the probable-effects-level (PEL) guidelines for toxic biological effects established by USEPA. for Zn, Cu, Pb. However, many samples in the main channel and east side from sites I, II, X and in main channel from sites V and VI contained Ni concentrations exceeded the PEL guideline in different seasons. However, the majority of sediment samples had Cd concentrations below PEL

guideline. A few exceptions reported for six samples at sites I, II, V, VI and X in different seasons.

Comparison of total heavy Nile metals with the background concentration cited by Salomons & Forstner (1984) and USPHS (1997). All Zn sediments concentrations showed higher levels than acceptable guideline and Cd levels at the majority of sites were more than 1µg/g. However, concentrations of Ni at the majority of sites were below the acceptable guideline with exception for three samples from the east at sites I, II and X, which can often be attributed to anthropogenic influences, rather than natural enrichment of the sediment by metals. In addition, the levels of Cu in most samples were in order of magnitude below the acceptable guideline, while Pb levels in ten samples from sites I, II, V, VI and X exceeded the background concentrations.

The present study reveals that urban centers may act as sources of Ni, Cu, Zn, Pb and Cd and cause metallic sediment contamination in the River Nile. Finally, it is important to determine the source of these heavy metals and to manage their input into the River Nile ecosystem so that their concentrations in the sediment do not reach toxic levels.

**Table (6): Sediment-quality guidelines of metals (µg/g) found in freshwater sediments**

Metal	USEPA (1997)		Salomons & Forstner (1984) USPHS (1997)	Present results evels
	TEL	PEL		
Zn	124	271	<100	102.2-261.35
Ni	15.9	42.8	45-65	10.0-70.67
Cu	18.7	108	45-50	1.93-62.6
Cd	0.68	4.21	1	0.58-12.61
Pb	30.2	112	20-30	2.2-52.2

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