

Heavy metal concentrations in surface river water and bed sediments at Nile Delta in Egypt

Raskasmetallipitoisuudet jokivedessä ja pohjasedimenteissä Niilin suistossa Egyptissä

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Rosetta Branch of river Nile is subjected to severe pollutants of domestic, sewage, agricultural and industrial pollution. In this study, the distribution of heavy metals (Al, Ba, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn) were measured in surface river water and the bed sediments of Rosetta Branch and the impacts of heavy metals on the water quality were monitored. The heavy metal concentrations in river water and their contents in the bed sediments were studied three times before, during and after winter period (low flow conditions) from August 2007 to April 2008. The heavy metal concentrations in the river sediments were remarkably high, but varied among sampling points, and the concentrations in water were mainly within the permissible limits. The heavy metal contents in bed sediment were highest during closure of winter period. Attention should be paid to mitigate element mobilization from sediments as their effects may become significant during seasons and years of low water flow in the river. Constant monitoring of the Nile river water quality is needed to record any alteration in the quality and mitigate outbreak of health disorders and the detrimental impacts on the aquatic ecosystem.

Keywords: River Nile, Nile Delta, Rosetta Branch, surface water, bed sediment, heavy metal, concentration, water quality, pollution

Introduction

Rosetta Branch is located in the west part of the Nile Delta in Egypt. It originates from the main sector of the Nile River at Delta Barrage and discharges into the Mediterranean Sea, its length is about 225 km, and the width varies from 150–200 m with the average depth of 2.3 m (Daifullah

et al 2003). Rosetta Branch receives considerable amounts of pollutants from agricultural areas and sewages. In addition, industrial plants at Kafr El-Zayat city on the banks of the branch (e.g. Soda, El-Malia and Kafr El-Zayat pesticides production) directly pour their effluents into the branch (Sohair et al 1993). El-Gohary (1990) pointed that, industry were identified as being the major source

of water pollution in this area. The metal industry represents about 50% of the total waste discharges and industrial effluents as well as agricultural and domestic sewages constitute a real threat to the aquatic ecosystems of River Nile (El-Matasseem 1987). The Physico-Chemical characteristics of the River Nile water have been rather widely monitored (e.g. Abol-Atta 1978, Mancy 1978, Saad 1980, Elewa and Mahdi 1988, Soltan 1988, Abdel Satar 1994, Elewa 1995, Ghallab 2000, and Elewa et al. 2001). However, the long-term effects of heavy metal pollution on the river water quality at River Nile delta are poorly known.

Heavy metals are among the most common environmental pollutants, and their occurrence in waters and biota indicate the presence of natural or anthropogenic sources. The main natural sources of metals in waters are chemical weathering of minerals and soil leaching. The anthropogenic sources are associated mainly with industrial and domestic effluents, urban storm, water runoff, landfill, mining of coal and ore, atmospheric sources and inputs rural areas (Kabata-Pendias & Pendias 1992, Biney et al. 1994, Zarazua et al. 2006). Water pollution by trace metals is an important factor in both geochemical cycling of metals and in environmental health (Kabata-Pendias and Pendias 1992). The existence of heavy metals in aquatic environments has led to serious concerns about their influence on plant and animal life. The nutritional requirements of elements (Cu, Zn etc.) differ substantially between species or elements, and optimum ranges of concentrations are generally narrow. Given elements (Pb, Cd etc.) exhibit extreme toxicity even at trace levels (Nicolau et al. 2006).

The aim of this current study is to clarify the spatial and temporal variation in heavy metal concentrations including aluminum (Al), barium (Ba), cadmium (Cd), cobalt (Co), chrome (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn) in surface water and bed sediment in Rosetta Branch at Nile Delta in Egypt. Furthermore, the role of pollutant sources in catchment of Rosetta Branch on the water quality were assessed as well as the interrelationships between heavy metal concentrations were analyzed.

Materials and methods

Study area

For water and bed sediments sampling, seven sampling points were chosen at the banks of Rosetta Branch (Table 1, Table 1). The sampling points were located at Delta Barrage (used as reference point), five drain outfalls (El-Rahway, Sabal, El-Tahreer, Zawyat El-Bahr and Tala, see Bakry 1990) and additional three industrial outfalls (Kafr El-Zayat) were chosen along Rosetta Branch. These drains were chosen, because they receive considerable amounts of waste water from industrial areas as well as from intensively cultivated agricultural areas and domestic wastes from 55 towns and villages (Donia & Farage 2005).

Water and bed sediment sampling

Nine water and bed sediment samples were collected once in three times before, during and after winter closure period from August 2007 to April 2008. Water samples were taken by using Van Dorn plastic bottles (1.5 liter capacity). The samples after collection were stored in the refrigerator at about 4 °C prior to analysis. The bed sediments were collected by scooping up 10 cm of the bed sediment from 10 m away from the riverbank at the point, where the water samples were taken, by using anti rust scoop and sediments were naturally dried at room temperature (25°C ± 2) in the laboratory prior to analysis.

Chemical and statistical analysis

The concentrations of Al, Ba, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn were measured using the Inductively Coupled Plasma – Optical Emission Spectrometry (ICP-OES) with Ultra Sonic Nebulizer (USN) (model: Perkin Elmer optima 3000). The samples were filtered by filtration system through membrane filter of pore size 0.45 µm before analyses using Standard Methods (APHA 1992). Bed sediment samples were digested using microwave digestion techniques as reported by Littlejohn et al (1991) in which 0.25 gm of sample was placed in Teflon vessel with 5 ml HNO₃

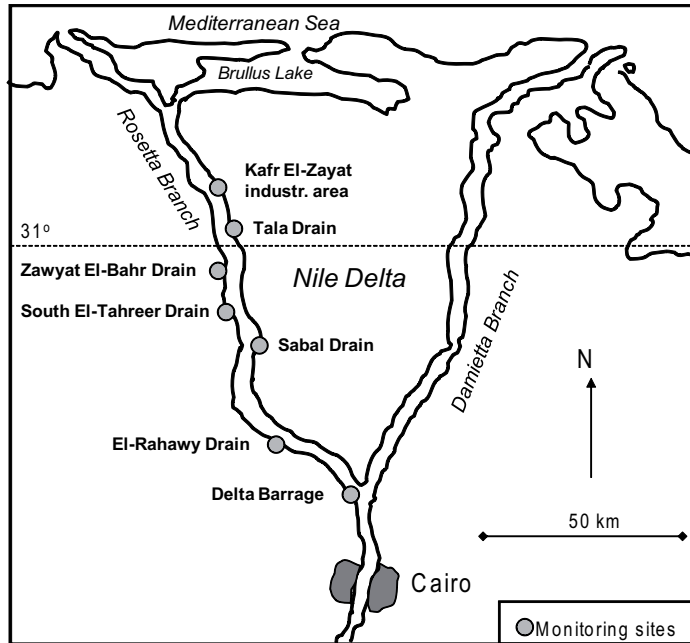


Figure 1. The locations of the sites, where the water and the bed sediment samples have been taken in Rosetta Branch, Nile River.

(65%), 2 ml HF (40%) and 2 ml H₂O₂ (30%) by using Microwave digestion system (model: MILESTONE mls-1200 mega). An aliquot of the filtration of the samples was taken (about 100 ml). Digestion solutions were measured for total heavy metals using ICP-OES (APHA 1995).

Correlation coefficients were calculated between all pairs of the measured element concentrations.

Results and discussion

Heavy metals in water

The means and ranges of element concentrations in the water samples are presented in Table 2. The results showed that, most of the heavy metal concentrations in surface water of Rosetta

Table 1. Location of the study sites in Rosetta Brach, Nile River.

Site		Latitude (N)	Longitude (E)
RF	Delta Barrage on Rosetta Branch	30°11'21.03"N	31° 6'34.08"E
D1	El-Rahawy drain outfall	30°12'26.53"N	31° 1'57.84"E
D2	Sabal drain outfall	30°32'14.15"N	30°51'6.79"E
D3	El-Tahreer drain outfall	30°36'24.74"N	30°47'49.24"E
D4	Zawyat El-Bahr drain outfall	30°42'52.97"N	30°45'41.80"E
D5	Tala drain outfall	49°30'54.01"N	48°30'68.47"E
C1	Soda and Salt Company outfall	49°30'72.36"N	48°30'94.21"E
C2	El-Malya El-Senaia Company outfall.	49°30'94.41"N	48°30'62.12"E
C3	Kafr El-Zayat pesticides production Company.	49°30'34.42"N	48°30'19.11"E

Table 2. The element concentrations measured from the water samples (mg l⁻¹). BWCP: Before winter period; DWCP: During winter period; AWCP: After winter period; LAW 48/1982: Egyptian Law for protection of the River Nile and water ways from pollution, Art. (60): for water quality in River Nile, Art. (61): for discharge treated industrial liquid effluent into River Nile, Art. (65): for discharge drain water into River Nile; FAO (1985): Food and Agriculture Organization Guidelines, 1985; CWQGs: Canadian water quality guidelines for the protection of aquatic life, 2002, — : No guideline available.

Heavy metal	Period	RF	DI	D2	D3	D4	D5	C1	C2	C3	LAW 48/1982	FAO (1985)	CWQGs
Al	BWCP	< 0.01	0.026	0.071	0.015	0.035	< 0.01	< 0.01	0.011	0.011	Art (60): —	5	—
	DWCP	0.026	0.363	0.092	0.034	0.307	0.186	0.069	0.072	0.070	Art (61): < 1		
	AWCP	0.022	0.057	< 0.01	< 0.01	< 0.01	0.068	0.055	0.060	0.057	Art (65): —		
	Mean	0.024	0.149	0.082	0.025	0.171	0.127	0.062	0.042	0.064			
Ba	BWCP	0.05	0.054	0.089	0.046	0.046	0.04	0.041	0.39	0.46	Art (60): —	—	1
	DWCP	0.025	0.15	0.083	0.053	0.036	0.083	0.085	0.093	0.089	Art (61): < 1		
	AWCP	0.016	0.029	0.061	0.025	0.019	0.016	0.061	0.069	0.064	Art (65): —		
	Mean	0.03	0.078	0.078	0.041	0.034	0.046	0.062	0.184	0.204			
Cd	BWCP	0.003	0.002	0.001	0.001	0.002	0.01	0.01	0.01	0.01	Art (60): 0.01	—	0.005
	DWCP	0.001	0.003	0.004	0.003	< 0.0005	< 0.0005	0.034	0.034	0.034	Art (61): < 1		
	AWCP	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	0.026	0.031	0.022	Art (65): 0.01		
	Mean	0.002	0.0025	0.0025	0.002	0.002	0.01	0.023	0.025	0.022			
Co	BWCP	< 0.005	< 0.005	0.007	0.009	0.006	0.01	0.01	0.01	0.01	Art (60): —	0.05	—
	DWCP	< 0.005	0.008	0.006	0.011	0.07	0.042	0.042	0.043	0.041	Art (61): < 1		
	AWCP	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.021	0.035	0.025	Art (65): —		
	Mean	< 0.005	0.008	0.007	0.01	0.038	0.026	0.024	0.029	0.025			
Cr	BWCP	0.004	0.018	< 0.002	0.005	0.008	0.012	0.011	0.012	0.01	Art (60): 0.05	0.1	0.05
	DWCP	0.003	0.003	0.005	0.007	< 0.002	< 0.002	0.055	0.056	0.056	Art (61): < 1		
	AWCP	0.001	< 0.002	0.004	0.005	< 0.002	< 0.002	0.041	0.044	0.046	Art (65): 0.01		
	Mean	0.003	0.011	0.005	0.006	0.008	0.012	0.036	0.037	0.037			
Cu	BWCP	0.018	< 0.002	< 0.002	< 0.002	< 0.002	0.005	0.007	0.005	0.004	Art (60): 1	0.2	1
	DWCP	0.012	0.018	0.019	0.018	0.023	0.039	0.035	0.04	0.041	Art (61): < 1		
	AWCP	0.004	0.008	0.011	0.01	0.013	0.017	0.021	0.026	0.021	Art (65): 1		
	Mean	0.011	0.013	0.015	0.014	0.018	0.02	0.021	0.024	0.022			
Fe	BWCP	0.164	< 0.01	0.079	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	Art (60): < 1	5	0.3
	DWCP	0.054	0.872	0.29	0.044	0.347	0.458	0.057	0.311	0.089	Art (61): < 1		
	AWCP	0.047	0.054	0.057	0.059	< 0.01	0.057	0.037	0.189	0.054	Art (65): 1		
	Mean	0.088	0.463	0.142	0.052	0.347	0.258	0.047	0.25	0.072			
Mn	BWCP	0.19	< 0.01	0.04	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	Art (60): 0.5	0.2–10	0.05
	DWCP	0.065	0.137	0.206	0.187	0.089	0.436	0.049	0.4	0.089	Art (61): < 1		
	AWCP	0.053	0.108	0.049	0.05	0.049	0.041	0.027	0.31	0.052	Art (65): 1.5		
	Mean	0.103	0.123	0.098	0.119	0.069	0.239	0.038	0.36	0.071			
Ni	BWCP	0.009	< 0.005	< 0.005	< 0.005	< 0.005	0.017	0.016	0.016	0.015	Art (60): —	0.2	—
	DWCP	< 0.005	< 0.005	0.008	0.019	< 0.005	0.034	0.034	0.032	0.033	Art (61): < 1		
	AWCP	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.008	0.025	0.024	0.025	Art (65): —		
	Mean	0.009	< 0.005	0.008	0.008	< 0.005	0.020	0.025	0.024	0.024			
Pb	BWCP	< 0.005	< 0.005	< 0.005	0.024	< 0.005	0.017	0.018	0.019	0.018	Art (60): 0.05	5	0.01
	DWCP	0.019	0.019	0.032	< 0.005	< 0.005	0.051	0.057	0.051	0.047	Art (61): < 1		
	AWCP	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.047	0.037	0.028	0.022	Art (65): —		
	Mean	0.019	0.019	0.032	0.024	< 0.005	0.038	0.037	0.033	0.029			
Zn	BWCP	< 0.005	0.026	0.071	0.011	0.035	< 0.005	< 0.01	0.011	< 0.01	Art (60): < 1	2	5
	DWCP	0.071	0.054	0.03	0.027	0.077	0.097	0.034	0.035	0.035	Art (61): < 1		
	AWCP	0.057	0.015	0.008	0.011	< 0.005	0.034	0.023	0.025	0.024	Art (65): 1		
	Mean	0.064	0.032	0.036	0.016	0.056	0.066	0.029	0.024	0.03			

branch were found within the permissible limits of both Egyptian law 48/1982 and FAO (1985). Agricultural and industrial activities are mainly responsible for elevated levels of the measured elements in river water. The mean values of the elements at different zones showed Fe to be the most abundant element in all points followed by Mn, Zn, Al, Cu, Ba and Ni. Al and Fe values ranged between <0.01 – 0.36 mg l^{-1} and <0.01 – 0.87 mg l^{-1} , respectively. The Fe concentrations were highest at the effluent point of El-Rahawy drain, where are significant metal industry in the surroundings such as welding of the iron pipes. Generally, given heavy metals concentrations were higher during winter closure period, which is due to smaller amounts of discharging water and the elements adsorb and precipitate on the sediment particles resulting from low pH values and microbial activity (Elewa & Goher 1999).

The sources of Al in fresh water include domestic wastes, manufacturing processes involving metals, and the dumped sewage sludge (James 1991). Most ferrous compounds in aquatic environments are resulting from the precipitation of Fe in alkaline and oxidizing conditions (Abdulla et al. 1973). The highly significant positive correlation ($r = 0.812$) between the concentrations of Fe and Al suggests that the association of the two elements originates from a common source as oxides and hydroxides and also during transportation and/or deposition processes (Degroot & Allersma 1975).

The concentrations of the analyzed elements in surface water were as following: Ba: 0.016 – 0.46 mg l^{-1} , Ni: <0.005 – 0.034 mg l^{-1} , Cu: <0.002 – 0.041 mg l^{-1} , Cr: <0.002 – 0.056 mg l^{-1} , Cd: <0.0005 – 0.034 mg l^{-1} and Pb <0.005 – 0.057 mg l^{-1} , respectively (Table 2). The low concentrations are probably related to the high pH values, which also seems to influence the concentration of these metals in natural unpolluted water (Tawfiq 1998). Ba was significantly positively correlated with Ni, Cu, Cd and Cr (Table 3). These findings may be related to the adsorption of the heavy metals by metal oxides or hydroxides. Major sources of these elements in fresh water include atmospheric deposition, contamination of water in natural geologic deposits, the composition of drilling mud and fluids, manufacturing processes related to chemicals and metals, discharges of municipal waste followed by smelting and refining of non-ferrous metals and domestic wastes (James 1991).

The concentrations of Mg and Zn during the winter closure period were lower than those after the winter period (Table 2), because of the increased consumption of this element by the phytoplankton (Emerson & Lewis 1939). Low Mg and Zn concentrations in the surface water may be related to the contribution of phytoplankton, pH and dissolved oxygen concentrations. The negative correlation between Mg and Zn concentrations ($r = -0.026$) is may be a result of precipitation of the elements as hydrous metal

Table 3. Correlation coefficient matrix for heavy metals of surface water during the period of August 2007– April 2008.

	Al	Ba	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Al	1										
Ba	-0.239	1									
Cd	-0.309	0.736	1								
Co	0.253	0.157	0.439	1							
Cr	-0.239	0.773	0.979	0.418	1						
Cu	0.011	0.658	0.88	0.737	0.852	1					
Fe	0.812	-0.070	-0.281	0.104	-0.214	-0.067	1				
Mn	-0.117	0.362	0.316	0.178	0.215	0.403	0.298	1			
Ni	0.298	0.611	0.958	0.95	0.925	0.934	0.246	0.255	1		
Pb	0.112	0.196	0.613	0.674	0.502	0.777	-0.194	0.268	0.651	1	
Zn	0.393	-0.482	-0.363	0.472	-0.453	-0.214	0.232	-0.026	-0.141	0.028	1

oxides (El-Sayed & El-Sayed 1980). The toxicity of Mg is relatively low. The permissible levels of Mg in water used for domestic purposes are quite low $<0.05 \text{ mg l}^{-1}$ and in water for continuous irrigation the maximum acceptable concentration is 0.2 mg l^{-1} (U.S. EPA 1972). The major sources of Mn and Zn are the domestic wastes, municipal wastes followed by dumping and atmospheric deposition (James 1991).

Heavy metals in sediments

Sediment contamination poses one of the worst environmental problems in ecosystems, acting as sinks and sources of contaminants in aquatic systems. Sediment analysis plays an important role in assessing the pollution status of the environment (Mucha et al. 2003).

Many heavy metals concentrations in sediment, especially in the fine grained sediment, which acts as a transport agent in the water column, are at least three orders of magnitude higher than the same metals in surrounding water. The analysis of heavy metal levels in sediment samples helps in the interpretation of water quality (Heiny & Tate 1997). The heavy metals are present in the river sediments as a result of urban discharge and industrial waste water beside of natural sources. The sediments are also used for determination of heavy metals when the concentrations in water are undetectable with present analysing methods (Soares et al. 1999).

Determination and speciation of heavy metal pollution is one of a primary target in environmental research (Warren & Zimmerman 1994; Nowack et al. 2001). Therefore, the analysis of heavy metals in sediments enables the detection of pollution deteriorating water quality and provides information about the "critical sites" of the water system (Fabbri et al. 2001 Bordes & Bourg 2001). Variations in the contents of studied elements in the river bed sediment were observed to be as following: Al: $10.1\text{--}40.4 \text{ g kg}^{-1}$, Ba: $284.4\text{--}1012.4 \text{ mg kg}^{-1}$, Cd: $0.2\text{--}4.5 \text{ mg kg}^{-1}$, Co: $15\text{--}40.4 \text{ mg kg}^{-1}$, Cr: $37.1\text{--}233.0 \text{ mg kg}^{-1}$, Cu: $11.8\text{--}60.20 \text{ } \mu\text{g kg}^{-1}$, Fe: $101.9\text{--}1008.6 \text{ mg kg}^{-1}$, Mn: $125\text{--}1008.2 \text{ mg kg}^{-1}$, Pb: $4.6\text{--}94.9 \text{ mg kg}^{-1}$, and Zn: $146.6\text{--}522.3 \text{ mg kg}^{-1}$, respectively, in each period (Table 4), while Ni concentrations in

all bed sediment samples showed extremely low concentrations ($<0.005 \text{ mg kg}^{-1}$), which are below the detection limits of the analysis (ICP-OES). The highest concentration values of most of the elements were observed during winter closure period (in low flow conditions). This phenomenon may be attributed to the increase in organic matter concentrations which facilitate settling of Fe to the sediment during hot seasons (Abdel-Satar & Elewa 2001), and the low element concentrations may be attributed to the mobilization of Fe from sediment to water (Elewa & Goher 1999). Mn was precipitated as MnO_2 under reducing conditions during winter (Abdo 2002). Zn was precipitated as zinc oxide and zinc carbonate, in addition to copper (See also Abdo 2004). However, the lower concentration values of these elements may be caused by their mobilization from sediment to overlying water due to the low pH values and microbial activity (Elewa & Goher 1999). These results are in accordance with results by Abdo (2004). On the other hand, the relative increase of Pb and Cd concentrations during winter may be related to the decaying of plankton and precipitation of organic matter associated with Pb and Cd to the sediment (see also Goher 1998). The maximum values of the studied element contents in the bed sediment were recorded at effluent discharges into Rosetta branch from El-Rahawy drain during winter closure period as following: Al: $14.75 \text{ } \mu\text{g kg}^{-1}$, Ba: $808.56 \text{ mg kg}^{-1}$, Fe: 60.20 g kg^{-1} , Mn: $701.96 \text{ mg kg}^{-1}$, Cu: 70.32 mg kg^{-1} , Co: 40.44 mg kg^{-1} , Cd: 1.04 mg kg^{-1} , Cr: 185.6 mg kg^{-1} , Pb: 14.24 mg kg^{-1} and Zn: $522.32 \text{ mg kg}^{-1}$, respectively. The high concentrations of Fe found in the sediments may be mainly result from the natural deposits and industry, where Fe is one of the chemicals used for drilling operations. However, the relative lower values of Fe at El-Rahawy drain outfall may be attributed to its adsorption on large amounts of dissolved organic matter. Also, according to Williams (1992), water of El-Rahawy drain contains a large amounts of H_2S which produced by sulfate reducing bacteria and anaerobic conditions. These conditions promote the precipitation of Fe as iron sulphide (FeS). Mn and Al precipitate as MnO_2 and Al_2O_3 under reducing conditions (Abdo 2002).

Pb values in the sediments consistently higher

Table 4. The element contents in bed sediment samples at Rosetta Branch (mg kg⁻¹, dry weight). BWCP: Before winter period, DWCP: During winter period, AWCP: After winter period, ISQGs: Interim freshwater sediment quality guidelines, PEL: probable effect levels, —: No guideline available, *): Screening Level Guidelines by Ontario Ministry of the Environment (Persaud et al. 1993).

Heavy Period metal		RF	DI	D2	D3	D4	D5	C1	C2	C3	ISQG	PEL (SEL)*	Server effect level
Al	BWCP	10085.2	26830.4	15544.8	18272.8	18495.2	13414.8	10128.4	11777.2	11301.6	—	—	—
	DWCP	14755.6	40422.8	24704.0	29533.2	34870.4	18260.4	19772.8	14462.8	13951.6			
	AWCP	12256.6	37853.2	22946.8	27169.2	27053.4	17305.2	16295.6	12739.2	11587.6			
	Mean	12365.5	35035.5	21065.2	24991.7	26806.3	16326.8	15398.9	12993.1	12280.3			
Ba	BWCP	339.0	675.8	311.8	474.1	324.6	284.4	370.04	324.6	330.0	500	750	—
	DWCP	457.4	808.6	480.0	574.5	677.8	414.1	1012.4	540.1	546.6			
	AWCP	421.3	715.2	416.0	517.6	476.6	366.2	687.60	426.8	477.2			
	Mean	405.9	733.2	402.6	522.1	493.0	354.9	690.01	430.5	451.3			
Cd	BWCP	0.24	0.56	0.48	0.36	0.32	0.68	1.20	0.72	0.36	0.6	3.5	10
	DWCP	0.44	1.04	0.96	0.80	0.84	3.12	4.52	2.87	2.76			
	AWCP	0.31	0.84	0.62	0.51	0.63	0.95	3.11	1.23	1.17			
	Mean	0.33	0.81	0.69	0.56	0.60	1.58	2.94	1.61	1.43			
Co	BWCP	15.0	26.90	17.30	21.30	19.08	14.68	19.92	28.28	27.56	40	300	—
	DWCP	16.70	40.40	25.80	32.60	32.68	35.96	26.60	32.44	30.12			
	AWCP	15.20	31.40	21.80	27.80	24.35	21.27	23.80	29.68	28.20			
	Mean	15.60	32.90	21.60	27.20	25.37	23.97	23.44	30.13	28.63			
Cr	BWCP	80.48	125.24	92.16	140.04	97.72	123.6	111.92	110.76	111.24	37.3	90	110
	DWCP	101.80	185.60	109.40	115.84	103.04	199.3	115.56	128.84	164.36			
	AWCP	95.21	171.60	103.60	133.16	112.23	136.1	117.14	107.80	113.80			
	Mean	92.50	160.81	101.72	129.68	104.33	153.0	114.87	115.80	129.80			
Cu	BWCP	80.12	69.52	70.64	37.08	39.36	59.64	170.6	175.16	181.28	35.7	197	110
	DWCP	94.44	70.32	55.96	130.28	78.68	68.24	244.96	330.76	332.96			
	AWCP	84.32	69.91	58.23	58.62	51.27	63.23	212.53	231.8	253.21			
	Mean	86.29	69.92	61.61	75.33	56.44	63.7	209.36	245.91	255.82			
Fe	BWCP	11777.4	44130.6	24954.8	25166.1	31068.2	15550.0	33148.1	51992.0	51416.0	—	—	—
	DWCP	14149.6	60197.5	35191.8	39449.7	38361.5	24251.8	47544.0	55108.9	53194.2			
	AWCP	12601.3	54005.1	31531.4	34287.9	35566.3	18800.2	36038.4	53644.4	52856.8			
	Mean	12842.8	52777.8	30559.3	32967.9	34998.7	19534.0	38910.1	53581.7	52489.0			
Mn	BWCP	199.32	452.32	449.24	810.72	451.56	361.32	101.88	116.96	125.00	—	—	—
	DWCP	264.64	701.96	516.08	1008.6	631.64	783.20	510.36	217.84	230.32			
	AWCP	211.60	623.60	467.80	927.40	527.20	580.40	492.11	166.80	145.20			
	Mean	225.19	592.63	477.71	915.57	536.80	574.97	368.17	167.20	166.84			
Ni	BWCP	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	21	52	75
	DWCP	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005			
	AWCP	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005			
	Mean	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005			
Pb	BWCP	7.84	5.80	5.28	4.64	6.40	15.48	43.32	51.12	81.60	35	91.3	250
	DWCP	8.44	14.24	48	11.48	8.64	17.24	71.12	94.84	92.96			
	AWCP	8.12	7.32	23.61	7.65	7.31	16.34	59.62	63.16	86.52			
	Mean	8.13	9.12	25.63	7.92	7.45	16.35	58.02	69.71	87.03			
Zn	BWCP	146.6	444.68	235.36	255.6	275.0	430.32	159.64	147.68	167.44	123	315	820
	DWCP	212.32	522.32	391.48	360.48	354.52	742.92	340.96	283.92	368.56			
	AWCP	187.30	487.31	285.62	314.24	321.24	531.26	236.80	245.13	264.22			
	Mean	182.07	484.77	304.15	310.11	316.92	568.17	245.80	225.58	266.74			

than Cd may be explained by the fact that Cd in sediment is associated with the carbonate fraction and concentrates on the suspended matter (Laxon 1985), and Cd will be mobilized from sediment to water (Goher 1998). Higher values of Cd were observed during winter closure period at El-Rahawy drain outfall. Pb was mainly associated with the Fe-Mn oxide fraction and had high retention in sediment (Fernandez et al. 2000). Domestic and industrial effluents are the major sources of the observed high level of Pb. Zn, Co, Cu, and Cr are mainly precipitated as soluble oxide (Abdo 2004). A residual fraction of Cr is buried in the bottom sediments as insoluble compounds.

The high concentrations of the studied elements may be attributed to the effect of intrusion of water borne Fe, Mg, Cu, Zn, Pb and Cd coming from agricultural, domestic and industrial effluents, and the small grain size of the sediment facilitates the adsorption of these metals to bottom sediments. The results of this study are mostly in accordance with earlier findings obtained from other aquatic environments in Egypt (Abdel-Satar 1998, Issa et al. 1996, Goher 2002). However, in our data, the concentrations of Fe, Mn, Zn and Pb are higher than e.g. in Qarun lake, where the ranges of those elements were found to be 8.08–44.72 mg g⁻¹ for Fe, 86.76–835.70 µg g⁻¹ for Mn, 17.56–742.34 µg g⁻¹ for Zn and 1.00–71.84 µg g⁻¹ for Pb concentrations, respectively (See, Goher 2002). Ibrahim et al. (1999) further reported that the ranges of Zn and Pb in El-Manzala lake sediments were found to be 65.70–137.50 µg g⁻¹ for Zn and 15.25–24.60 µg g⁻¹ for Pb. The

concentrations of Cu and Cd in the Bardawil lake sediments were found to be higher than those in Qarun lake (Goher 2002) and in Manzala lake (Ibrahim et al. 1999).

The results suggest that Cd has an environmental behaviour similar to that of Fe, Mn, Zn and Pb (Abdo 2002 and Abdo 2004). Fe and Mg oxides can play a role in the retention of trace metals. These elements in solution can be adsorbed by hydroxides or co-precipitate with them when the physical and chemical conditions change in water body. The positive correlations between Cd, Cu and Pb as well as between Cu and Fe (Table 5) indicated that Cu is strongly associated with Fe and it may co-precipitate or adsorbed on manganese oxide or hydroxide (Lin & Benjamin 1992, Bertin & Bourg 1995).

Generally, the element mobilization in the sediment environment is dependent on physicochemical changes in the water at the sediment–water interface. The precipitation of heavy metal elements in the form of insoluble hydroxides, oxides and carbonates might be the result of alkaline pH. The given elements, such as Cr, Cu and Co have interacted with organic matter in the aqueous phase and settled resulting in a high concentration of these elements in the sediment (Pardo et al. 1990 and Facetti et al. 1998). According to USEPA criteria, Cr, Pb and Zn in the sediment are categorized as ‘non-pollutant’, Ni is ‘moderate pollutant’ and Cu is categorized as ‘heavy pollutant’ (see criteria by USEPA) Mineralogical studies of polluted sediments indicate that heavy metals are found to be associated with

Table 5. Correlation coefficients for elements in the bed sediment samples during the period of August 2007– April 2008.

	Al	Ba	Cd	Co	Cr	Cu	Fe	Mn	Pb	Zn
Al	1									
Ba	0.567	1								
Cd	-0.411	0.311	1							
Co	0.461	0.454	0.153	1						
Cr	0.417	0.343	0.168	0.675	1					
Cu	-0.618	0.073	0.652	0.296	-0.070	1				
Fe	0.215	0.487	0.302	0.873	0.342	0.607	1			
Mn	0.704	0.238	-0.314	0.174	0.391	-0.693	-0.209	1		
Pb	-0.616	-0.028	0.645	0.293	-0.049	0.962	0.607	-0.688	1	
Zn	0.499	0.090	-0.016	0.352	0.828	-0.489	-0.053	0.523	-0.399	1

fine particles of silt clay that have large surface areas and they to adsorb and accumulate ions due to their intermolecular forces.

Conclusions

The results showed that the heavy metal element concentrations in River Nile water at Nile Delta were mainly within the permissible limits according to e.g. Egyptian law (48/1982) and criteria by FAO (1985). However, significant local water pollution problems were found. Due to the increasing swept-out effluents along different drains into the River Nile and extensive water use, the quality of river water is exposed to deterioration. In recent years, the impact of the wastes discharged on ambient water quality of the Nile has not been significant due to the high self-assimilation capacity of the river water. The heavy metal concentrations in the river sediments were remarkably high, but varied among sampling points. Our results suggest that special attention must be given to

the issue of element re-mobilization, because a large portion of elements in sediments are likely to release back into the water column. Special attention should be paid to mitigate pollution from these sources as their effects may become significant during seasons and years of low water flow in the river. Therefore, constant monitoring of the Nile river water quality is needed to record any alteration in the quality and mitigate outbreak of health disorders and the detrimental impacts on the aquatic ecosystem.

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References

- Abdel-Satar, A.M. 1998. Distribution of some chemical elements in the River Nile environments at great Cairo Region. Ph. D. Thesis, Fac. Sci. Cairo Univ., 249 pp.
- Abdel-Satar, A.M. & Elewa, A.A. 2001. Water Quality and Environmental Assessments of the River Nile at Rosetta branch. 2nd International Conference and Exhibition for Life and Environment. 3 (5): 136–164.
- Abdo, M.H. 2002. Environmental studies on Rosetta branch and some chemical applications at the area extend from El-Kanater El-Khyria to Kafr El-Zayt city. Ph.D. Thesis, Faculty of Science, Ain Shams University, Egypt, 187 pp.
- Abdo, M. H. 2004. Environmental studies on the River Nile at Damietta branch region, Egypt. J. Egypt. Acad. Soc. Environ. Develop. 5 (2): 85–104.
- Abdulla, M.I., Dunlop, H.M. & Gardner, D. 1973. Chemical and hydrographic observations in the Bristol Channel during April and June 1971, J. Mar. Biol. Assoc. U. K., 36, 509–17.
- APHA. 1992. American public health association ‘‘APHA’’ Standard methods for the examination of water and wastewater. Washington, D.C. USA, 18th edn. 536 pp.
- APHA. 1995. American public health association ‘‘APHA’’ Standard methods for the examination of water and wastewater. Washington, D.C. USA, 19th edn. 698 pp.
- Bakry, M.F. 1996. The data collected concerning a water quality condition on Damietta and Rosetta branches during 1993.’’ Res. Inst. of Channel Maintenance, Nat. Wat. Centre J. 20: 146–150.
- Bertin, C. & Bourg, A.C.M. 1995. Trends in the Heavy Metals Content (Cd, Pb and Zn) of River Sediments in the Drainage basin of Smelting Activities. Wat. Res., 29: 1729–1736.

- Bordes, P. & Bourg, A. 2001. Effect of solid/liquid ratio on the remobilization of Cu, Pb and Zn from polluted river sediment. *Water, Air and Soil Pollution* 128: 391–400.
- Canadian Council of Ministers of the Environment. 2002. Canadian sediment quality guidelines for the protection of aquatic life: Summary tables. Updated. In: Canadian environmental quality guidelines, 1999. Canadian Council of Ministers of the Environment, Winnipeg. pp: 1–10.
- Daifullah, A.A.M., Elewa, A.A., Shehata, M.B. & Abdo, M.H. 2003. Evaluation of some heavy metals in water, sediment and fish samples from the Nile River (Kafr El-Zayat city), Egypt. *Afric. J. Environ. Asse. Manag.* 6, 16–31.
- Degroot, A.J. & Allersma, E. 1975. Field Observation on the Transport of Heavy Metals in Sediments, *Heavy Metals In The Aquatic Environment*, P. A. Krenkel (Ed.), Pergamon Press, New York, 126 pp.
- Donia, N. & Farage, H. 2005. Development of the Nile River Water Quality Information System, Egypt. Ain Shams University, 1st International Conference, pp: 9–11.
- Egyptian Law (48/1982). The Implementer Regulations for law 48/1982 regarding the protection of the River Nile and water ways from pollution. *Map. Periodical Bull.* 3–4 Dec.: 12–35.
- Elewa, A.A. & Mahdi, H. 1988. Some liminological studies on the Nile water at Cairo, Egypt. *Bull. Nat. Inst. Oceanogr. & Fish., A.R.E.* 14 (2): 141–142.
- Elewa, A.A. 1991. Influence of flood water on the physical and chemical features of Lake Nubia, Sudan, *Bull. Nat. Inst. Oceanogr. & Fish., A.R.E.* 17 (1): 97–109.
- Elewa, A.A. & Goher, M.E.M. 1999. Environmental factors affecting the precipitation and dissolution of Fe, Mn, Zn, Cu, Pb and Cd in River Nile at Damietta branch. *Bull. Fac. Sci., Zagazig Univ.* 21 (2): 114–136.
- El-Gohary, F.A. 1990. Waste water management in Shubra El-Kheima. 2nd Egyptian Seminar on Industrial Waste water Management, Cairo, Egypt: 1–21.
- El-Sayed, M.A. & El-Sayed, M.Kh. 1980. Levels of heavy metals in the surface water of a semi-enclosed basin along the Egyptian Mediterranean coast. *Vas Hournees Etud. Pollution Commission Internaional pour l'Exploration Scientifique de la Mer. Mediterance (C.I.E.S.M.)*, Monaco, 225–233 pp.
- Emerson R. & Lewis C.M. 1939. Factors influencing the efficiency of photosynthesis, *Amer. J. Boto.* 26: 808–822.
- FAO. 1985. Water quality guidelines for agriculture, surface irrigation and drainage. Food and Agriculture Organization. Rev. 1, 29 pp.
- Fabbri, P., Gabbianelli, G., Locatelli, C., Lubrano, P., Tormbini, C. & Vassura, I. 2001. Distribution of mercury and other heavy metals in core sediments of northern Adriatic Sea. *Water, Air and Soil Pollution* 129: 143–153.
- Facetti, J., Dekov, V.M. & Grieken, R.V. 1998. *Science of the Total Environment* 209: 79–86.
- Fernández, M., Cuesta, S., Jiménez, O., García, M.A., Hernández, L.M., Marina, M.L. & González, M.J. 2000. Organochlorine and heavy metal residues in the water of the Southeast Regional Park in Madrid, Spain. *J. Chemosphere*, 41:801–812.
- Goher, M.A. 1998. Factors affecting the precipitation and dissolution of some chemical elements in River Nile at Damietta branch. M.Sc. Thesis fact. of Sci. Menofia Univ. Egypt, 189 pp.
- Goher, M.A. 2002. Chemical studies on the precipitation and dissolution of some chemical elements in Lake Qarun, Ph.D. Thesis, Fac., of Sci., Azhar Univ. Cairo, Egypt, 153 pp.
- Gomaa, M.N.E. 1995. Recycling study of some heavy metals in the Egyptian. *J. Aquatic Ecosystem. Food Chemistry.* 54: 297–303.
- Heiny, J.S. & Tate, C.M. 1997. Concentrations, distributions and comparison of selected trace elements in bed sediment and fish tissue in the South, Platte, River, Basin, USA, 1992–1993. *Archives of Environmental Contamination and Toxicology* 32: 246–259.
- Ibrahim, A.M., Bahnasawy, M.H., Mansy, S.E. & El-Fayomy, R.I. 1999. Heavy metals accumulation in water, sediment and some fishes in Lake Manzala, Egypt. *J. Egypt. Ger. Soc. Zool.* 29(B) *Vertebrat Anatomy & Embryology*: 43–58.

- Issa, Y.M., Elewa, A.A., Rizk, M.S. & Hassouna, A.F.A. 1996. Distribution of some heavy metals in Qaroun Lake and River Nile, Egypt. *Menofiya Journal of Agricultural Research* 21: 733–746.
- James, W.M. 1991. Inorganic contaminations of surface water: Research and monitoring properties. Springer-Verlag, New York, 334 pp.
- Laxen, D.P.H. 1985. Trace metal adsorption/co-precipitation of hydrous ferric oxide under realistic conditions. *Water Resources* 19: 1229–1236.
- Lin, C.F. & Benjamin, M.M. 1992. The effect of strongly complexing ligands on the adsorptive partitioning on metal ion. *Water Resources* 26: 397–407.
- Littlejohn, D., Egila, J.N., Gosland, R.M., Kunwar, U.K. & Smith, C. 1991. Graphite furnace analysis. *Analytica Chimica Acta* 50: 71–84.
- Massoud, S.A.H. & Mahadi, H.A. 1985. Limnological investigation of Rosetta branch of the River Nile, Egypt. I. Environmental conditions. *Journal of Fresh Water Biology* 15: 645–653.
- Mucha, A.P., Vasconcelos, M.T.S.D. & Bordalo, A.A. 2003. Macro benthic community in the Douro Estuary: relations with heavy metals and natural sediment characteristics. *Environmental Pollution* 121: 169–180.
- Nowack, B., Kari, F.G. & Kruger, H.G. 2001. The remobilization of metals from iron oxides and sediments by metal- EDTA complex. *Water Resources* 30: 1922–1935.
- Pardo, R., Barrado, E., Perez, L. & Vega, M., 1990. *Wat Res.*, 1990, 24(3), 373–379.
- Persaud, D., Jaagumagi, R., & Hayton, A. 1993. Guidelines for the protection and management of aquatic sediment quality in Ontario. ISBN 0-7729-9248-7. Ontario Ministry of the Environment, Ottawa, Ontario. 23 pp.
- Riley, J. P. & Skirrow, G. 1975. *Chemical Oceanography*, London. 647 pp.
- Soares, HMVM., Boaventura, RAR., Machado, AASC. & Esteves de Silva, JCG. 1999. Sediments as monitors of heavy metal contamination in the Ave river basin (Portugal): multivariate analysis of data. *Environmental Pollution* 105: 311–323.
- Sohair, I.A.-E. & Aly, N.E. 1993. Pollution in the River Nile; Assessment and control;” A case of study - Nile 2002 Conference, Aswan, Egypt. 2: 1–15.
- Tawfiq, M.E.F. 1998. Seasonal distribution of cadmium in Lake Nasser, Aswan reservoir and River Nile at Aswan.” *Monoufia Journal of Agricultural Research* 32: 391–414.
- U.S. EPA 1972. U.S. Environmental Protection Agency. *Water Quality Criteria*, National Academy of Sciences, pp 108–118.
- Warren, L.A. & Zimmerman, A.P. 1994. The influence of temperature and NaCl on Cadmium, Copper and Zinc partitioning among suspended particulate and dissolved phases in an Urban River. *Water Resources* 28: 1921–1931.
- Williams, T.M. 1992. *J. Envir. Geol. Wat. Sci.*, 20: 117–124.

Tiivistelmä:**Raskasmetallipitoisuudet jokivedessä ja pohjasedimenteissä Niilin suistossa Egyptissä**

Niilin suistossa oleva joen läntisin Rosettan haara kuormittavat voimakkaasti teollisuuden ja yhdyskuntien jätevedet sekä maatalousalueilta tulevat huuhtoumat. Tässä selvityksessä monitoroitiin Niilin veden ja pohjasedimentin raskasmetallipitoisuuksia Rosettan haarassa syys- ja talvikauden ajan elokuun 2007 ja huhtikuun 2008 välisenä aikana, jolloin tapahtuu pääosa joen vuotuisesta virtaamasta. Mitatut raskasmetallit tai muut haitalliset alkuaineet olivat alumiini (Al), barium (Ba), kadmium (Cd), koboltti (Co), kromi (Cr), nikkeli (Ni), lyijy (Pb), kupari (Cu), rauta (Fe), mangaani (Mg) ja sinkki (Zn). Lisäksi tarkasteltiin mitattujen alkuaineiden välisiä riippuvuuksia ja verrattiin tuloksia aikaisempiin tutkimustuloksiin ja käsityksiin niiden merkityksestä veden laatuun. Mittaustulokset osoittivat, että jokiveden raskasmetallipitoisuudet olivat verraten korkeita, mutta pitoisuudet eivät ylittäneet kansainvälisiä normeja, jolloin haitallisia terveysvaikutuksia alkaisi esiintyä. Pitoisuudet olivat korkeimpia vähän veden aikaan keväällä. Jatkossa huomiota tulisi kiinnittää varsinkin aineiden liikkeellelähtöön pohjasedimenteistä, joka voi olla merkittävää vähävetisinä vuodenaikoina tai vuosina. Rosettan haaran rannoilla on monia riskikohteita ja -alueita, jotka voivat uhata jokiveden laatua. Jatkuva vedenlaadun seuranta olisi tarpeen, jotta laatumuutokset havaittaisiin ja terveyshaittoja sekä ekosysteemiin kohdistuvia vahinkoja voitaisiin ehkäistä.

Avainsanat: Niili, Niilin suisto, Rosettan haara, jokivesi, pohjasedimentti, raskasmetalli, pitoisuus, vedenlaatu, saastuminen