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ASSESSMENT OF HEAVY METAL POLLUTION IN SURFACE MUDDY SEDIMENTS OF LAKE BURULLUS, SOUTHEASTERN MEDITERRANEAN, EGYPT

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ABSTRACT

The concentrations of certain heavy metals (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pd and Zn) in the total and labile fractions of muddy sediment samples collected from eleven sites in Lake Burullus in January 2003 were investigated in order to evaluate the pollution status of the Lake. The metal contents were determined by means of Atomic Absorption Spectrophotometer (AAS) using MESS-2 certified reference material (National Research Council of Canada). The average concentrations of the heavy metals analyzed in total sediment fractions exhibited the following decreasing order: Fe > Mn > Cu > Ni > Zn > Cr > Pb > Co > Cd, while the average concentrations of the heavy metals analyzed in the labile fraction followed the order: Fe > Mn > Cu > Ni > Pb > Zn > Co > Cr > Cd. The concentrations of all studied heavy metals ranged between the Effect Range-Low (ERL) and the Effect Range-Median (ERM) for most studied locations. Metal pollution index (MPI) shows very high values for both total and labile fractions at all the examined locations. Field observation reveals that Lake Burullus received industrial, agricultural and domestic sewage, suggesting that anthropogenic input is the main source of heavy metal contamination. Health hazard calculations for the contaminated sediments exhibited a possibility of health risk due to long-term exposure of the human to the polluted sediments of Lake Burullus.

INTRODUCTION

Lake Burullus is a coastal lagoon situated along the Mediterranean Sea, between the western Rosetta and the eastern Damietta branches of the River Nile. The Lake is shallow and its average depth ranges from 0.5 to 2.1 meter. Seven drains are connected to Lake Burullus (El-Burullus drain, El-Gharbia drain, Nasser Drain, Drains 7, 8, 9 and 11) which are leading to daily input of pollutants to the Lake Burullus (Fig. 1).

Heavy metals are of the serious pollutants in natural environment due to their toxicity, persistence and bioaccumulation problems. The impact of anthropogenic perturbation is most strongly felt by estuarine and coastal environments adjacent to urban areas. Heavy metals from incoming drains, tidal and fresh water sources are rapidly removed from water body and deposited onto the sediments. Naturally occurring heavy metals usually originate from weathering of rock substrates and reach costal areas through rivers in the form of particulate material. These metals are mainly chemically bound to aluminosilicates, which are not readily bioavailable. However, metals of anthropogenic origin are more loosely bound in sediments and thus are more readily available to organisms (Schropp and Windrom, 1988). Analysis of the labile (leachable) metal fraction of the sediment may be more useful, in terms of discovering its biological significance and the new inputs, than analysis of the total metal fraction (Lacerda *et al.*, 1992; Puente *et al.*, 1996). However, sediment analysis is more indicative rather than water analysis for evaluating the degree of contamination in the aquatic medium due to the stable image over time for the sediment compared with the huge temporal variability in levels of contaminants in water. Furthermore, concentrations of toxic elements are usually higher in sediments with less possibility of contamination of samples during handling and processing, and the analytical methods are simpler.

Heavy metals such as cadmium, mercury, lead, copper and zinc are regarded as serious pollutants of aquatic ecosystems because of their environmental persistence, toxicity and ability to be incorporated into food chains (Förstner and Wittman, 1983). In Lake Burullus, industrial, agricultural and domestic wastes discharges have increased the levels of heavy metals in the lake.

The aim of this study was to investigate the degree of heavy metals pollution and the health hazard due to exposure to the contaminated sediments of Lake Burullus.

MATERIALS AND METHODS

Selection of sampling stations for sediment sampling from Lake Burullus included the outlets of canal, streams, and drains from industrial areas into the lake. Surface sediment (<4 cm) samples were collected from 11 sampling sites (Fig. 1) in January 2003. Surface layer is usually permanently oxidized and thus acts as a barrier to metals that migrate from deeper, reduced areas towards the surface and are retained by iron and manganese oxides. The surface layer of sediments controls the exchange of metals between sediments and water and constitutes a reserve of metals to which benthic organisms are exposed. Samples were transferred into labeled polyethylene bags and stored in the laboratory at –20 °C until analysis.

Sediment samples (100% Mud) were dried in an oven at 105 °C to constant weight (72 h), then ground and sieved. For total heavy metals analysis, 0.2 ± 0.02 g duplicate subsamples were weighed into digestion Teflon bombs and a 3:1 mixture (6 ml) of conc. HNO_3 (17M) and HCl (12M) (Breder, 1982) was added and heated at 80 °C until digestion was completed. The digests were allowed to cool and quantitatively transferred into 10 ml volumetric flasks made up to mark using deionized water. The digestion mixture was transferred into 20 ml polypropylene bottles ready for analysis. Reagent blanks were prepared in a similar manner for every batch.

The labile fraction was extracted from 0.5 ± 0.05 g using 40 ml of 1N HCl at room temperature; samples were shaked for 2 h, centrifuging at 5000 rpm for 2 min and filtered in 50 ml polypropylene bottles ready for analysis (Villares *et al.*, 2003).

The resulting solutions were analyzed using an air-acetylene flame atomic absorption spectrophotometer (AAS) (Perkin Elmer, Model 2380) at optimum instrument operating conditions recommended by the manufacturer. The results were expressed in mg kg^{-1} dw (UNEP/FAO/IAEA/IOC, 1984). The absorption wavelength and detection limits were as follows: 228.8 nm and 0.04 mg kg^{-1} for Cd; 240.7 nm and 0.05 mg kg^{-1} for Co; 357.9 nm and 0.06 mg kg^{-1} for Cr; 324.7 nm and 0.06 mg kg^{-1} for Cu; 248.3 nm and 0.8 mg kg^{-1} for Fe; 279.5 nm and 0.07 mg kg^{-1} for Mn; 232.0 nm and 0.09 mg kg^{-1} for Ni; 217.0 nm and 0.8 mg kg^{-1} for Pb; 213.9 nm and 0.7 mg kg^{-1} for Zn, respectively.

Reagents of analytical grade were utilized for the blanks and calibration curves. Precision was checked against standard reference material, provided by the National Research Council of Canada (MESS-2 marine sediment) and lied within the range of certified values with 91~97% recovery for all metals studied.

To prevent contamination, all used glass and plastic lab-ware were previously washed in dilute nitric acid and deionized water.

RESULTS AND DISCUSSION

The concentrations of heavy metals (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pd and Zn) of total and labile fractions are shown in Table 1 and 2, respectively. The average concentrations of heavy metals in total fraction can be arranged in the decreasing order Fe > Mn > Cu > Ni > Zn > Cr > Pb > Co > Cd and the average concentrations of heavy metals in labile fraction in the order Fe > Mn > Cu > Ni > Pb > Zn > Co > Cr > Cd.

Iron (Fe) concentrations were ranged between 12755 to 45869 mg kg^{-1} in total fraction; and 2303 to 8997 for labile fraction, which recorded the new input metals. The ratio of the heavy metal concentrations in the labile fraction to the total concentrations of metals in the sediment, expressed as a percentage, is known as the percentage of extractability. This has been used as a theoretic estimate of the relative importance of metal of anthropogenic origin (Carral *et al.*, 1994) and refers to the new input percentage (NIP) of heavy metals (Table 3). NIP for Fe fluctuated between 15.14 at site 2 to 32.45% at site 9. The maximum concentration of Fe was recorded at site 9 (45870 mg kg^{-1}), which is facing Brimbal fresh water Canal. The maximum concentration of Fe intotal fraction was 1.5 times more the that recorded in sediments of Danube River (29700 mg kg^{-1}) (Woitke *et al.*, 2003) and 2 times of that recorded in sediment of NW Spain (22957 mg kg^{-1}) (Villares *et al.*, 2003). On the other hand, the maximum concentration of Fe (8997 mg kg^{-1}) in the labile fraction was 2.7 times of that recorded in labile fraction in sediments of NW Spain (3362 mg kg^{-1}) (Villares *et al.*, 2003).

Manganese (Mn) concentrations fluctuated between 1311 to 4008 and 1144 to 3588 mg kg^{-1} for total and labile fractions, respectively. The NIP for Mn ranged between 74.11 and 90.95%, which indicates that most Mn recorded was new input to the lake. The maximum concentrations of Mn recorded for total and labile fractions in this study were 8.5 and 55 times of that recorded in the total and labile fraction, respectively, in sediments of NW Spain (Villares *et al.* 2003). The average concentration of Mn (2069 mg kg^{-1}) in total fraction was 2.5 time of that of Danube river (819 mg kg^{-1}) (Woitke *et al.*, 2003).

Copper (Cu), which is regarded as a serious pollutant of aquatic ecosystems, was the third higher in concentration during this study in both total and labile fractions. Cu concentrations fluctuated between 32.27 to 167.1 mg kg^{-1} for total fraction and 28.25 to 109.75 mg kg^{-1} for labile fraction with NIP from 45.14 to 87.54%. The highest NIP was recorded at site 5, which is located at the center of the lake (Fig. 1). However, only site 5 recorded a lower Cu concentration (32.27 mg kg^{-1}) than the Effect Range-Low value (ERL = 34 mg kg^{-1}), while the other 10 studied sites showed higher concentration values than ERL but lower than the Effect Range-Median value (ERM = 270 mg kg^{-1}) (Table 1). The average concentration of Cu in this study was 113 ± 43.7 mg kg^{-1} (for total fraction), which is 2 times that recorded for Danube river (65.7 ± 12.3 mg kg^{-1}) (Woitke *et al.*, 2003) and 10 times for NW Spain (10.87 ± 15.79 mg kg^{-1}) (Villares *et al.*, 2003).

Nickel (Ni) is one of the major elemental concentrations on the earth, constituting about 2% by weight (Nriagu, 1980). In this study, Ni concentrations ranged between 64.2 to 115.7 mg kg^{-1} for total fraction and 48 to 68 mg kg^{-1} for labile fraction with NIP between 58.8 to 90%. All studied locations except site 11 recorded NIP over 66%, which suggested a highly new input of Ni in the lake during the last few years. The average concentration of Ni in this study was 78.45 ± 13.57 mg kg^{-1} (for total fraction), which is 1.6 times that recorded for Danube river (49.6 ± 6.1 mg kg^{-1}) (Woitke *et al.*, 2003). However, Ni is present in significant concentrations in industrial and municipal discharges (3.8×10^6 kg $year^{-1}$), particularly in steel mill and electroplating wastes. Dissolved nickel levels in unpolluted fresh water usually range from 1 to 3 μg l^{-1}, and input from mixed industrial urban sources may increase to 10-15 μg l^{-1} (Snodgrass, 1980). Nickel and its compounds caused a variety of cancer in rodents and are listed as possible causative agents for occupational or environmental cancer in man (Dunnick *et al.*, 1995), but its toxicity toward aquatic biota is not well known.

Zinc (Zn) concentration values recorded in this study ranged between 44.83 to 141.37 mg kg^{-1} with an average value 78.41 ± 27.45 mg kg^{-1} in the total fraction and 30.53 to 84.69 mg kg^{-1} with an average value 50.67 ± 15.6 mg kg^{-1} in the labile fraction. NIP of Zn ranged between 45.19 to 86.57%, indicating that over 60% of Zn concentration detected in Lake Burullus was a new input. However, the concentrations of Zn recorded for the eleven studied locations were not exceeding the ERL value (150 mg kg^{-1}). The average concentration of Zn in total fraction was 40% of the average concentration recorded for Danube river (187 ± 25 mg kg^{-1}) (Woitke *et al.*, 2003) and 2 times that recorded for NW Spain (41 ± 27.1 mg kg^{-1}). However, the average concentration of Zn in labile fraction was 4.2 times that for NW Spain (11.9 ± 16.4 mg kg^{-1}) (Villares *et al.*, 2003).

Chromium (Cr) concentrations fluctuated between 50.81 to 81.98 mg kg^{-1} with average value 62.26 ± 10 mg kg^{-1} in the total fraction and 15.09 to 48.15 mg kg^{-1} with average value 29.16 ± 10.52 mg kg^{-1} in the labile fraction. NIP for Cr ranged between 25.17 to 66.67% with only five locations recording NIP over 50%. The Cr concentrations in the total fraction were lower than the ERL value (81 mg kg^{-1}) for all studied locations except site 11 (81.98 mg kg^{-1}), which lies near to Brimbal fresh water Canal. However, the average concentration of Cr in total fraction was much closer to that reported in Danube river (64 ± 12.3 mg kg^{-1}) while it was 4.6 times that reported for NW Spain (14.46 ± 10.48 mg kg^{-1}).

The concentrations of lead (Pb) in this study fluctuated from 46.18 to 80.35 mg kg^{-1} with average value 60.18 ± 12.5 mg kg^{-1} in the total fraction and 31.70 to 69.85 mg kg^{-1} with average value 50.9 ± 12.07 mg kg^{-1} in the labile fraction. Pb exhibited NIP from 68.34 to 91.26%, indicating a highly new input of Pb to the Lake. Total fraction showed Pb concentrations over the ERL value (46.7 mg kg^{-1}) for all the studied locations except sites 6 and 8 (Table 1) but much lower than the ERM value (218 mg kg^{-1}). However, total fraction showed average concentration of Pb ~1.3 times that reported for both of Danube river (46.3 ± 6.8 mg kg^{-1}) and NW Spain (43.3 ± 27.1 mg kg^{-1}), while it was 4.3 times that reported for labile fraction of NW Spain (11.9 ± 16.4 mg kg^{-1}).

The concentrations of cobalt (Co) fluctuated between 35.05 to 76.9 mg kg^{-1} with average value 44.9 ± 11.65 mg kg^{-1} in the total fraction and 26.37 to 59.15 mg kg^{-1} with average value 35.41 ± 8.97 mg kg^{-1} in the labile fraction. Co recorded NIP values between 65.79 and 91.57%, which suggested a highly new input of Co to the Lake. The average concentration of Co in this study was 8.5 and 120 times the total and labile fractions, respectively, of Co average concentration reported for sediments in NW Spain.

Cadmium (Cd) concentrations ranged between 7.4 to 12.34 mg k^{-1} with average concentration 9.59 ± 1.46 mg kg^{-1} in the total fraction and 5.05 to 8.33 mg kg^{-1} with average value 6.84 ± 1.03 mg

kg^{-1} in the labile fraction. Cd recorded NIP values between 54.71 and 93.15%, which suggested a highly new input of Cd to the Lake. Cd is contained in some phosphate-based fertilizers. Such sources could constitute a major source of Cd that may reach humans. In addition, sewage sludge from wastewater treatment may contain significant quantities of Cd. Cd is also a by-product of Zn smelting (Alloway, 1990). The application of sewage sludge and tailings from mines into landfills is another potential source of Cd contamination. In this study, total fraction exhibited Cd concentrations over the ERL value (1.2 mg kg^{-1}) for all studied locations and over the ERM value (9.6 mg kg^{-1}) for sites 3, 5, 7 and 10 (Table 1). The average concentration of Cd in this study was 8 times the total fractions reported for sediment of Danube river (1.2 ± 0.4 mg kg^{-1}).

Metal pollution index

The overall metal contents of total and labile fractions at the sites investigated in this study were compared, using the metal pollution index (MPI) calculated according to Usero *et al.* (1996 and 1997) with the formula:

$$MPI = (Cd \times Co \times Cr \times Cu \times Fe \times Mn \times Ni \times Pb \times Zn)^{1/9}$$

MPI ratios ranged between 115.74 to 252.57 with average 162.51 for total fraction and 72.36 to 121.09 with average 92.51 for labile fraction (Tables 1 and 2). MPI exhibited high values due to the higher concentrations of all studied metals especially Fe, Mn, Cu and Zn. Therefore, MPI suggested highly polluted sediments of Lake Burullus.

Statistical analysis

Spearman (Non-Paramatic) rank order correlations for studied heavy metals concentrations in total and labile fractions are summarized in Tables 4 and 5, respectively. Total fractions exhibited poor positive correlations for most of the metals, while for Cd, Co, Cr and Fe concentrations were significant ($p < 0.05$). The positive correlations ($P < 0.008$) were recorded between Mn vs Fe ($r = 0.75$); Mn vs Cr ($r = 0.88$); Co vs Cr ($r = 0.80$) and Co vs Ni ($r = 0.76$). Negative correlations were recorded between Cd vs Cr ($r = -0.68$) and Cd vs Fe ($r = -0.58$) (Table 4). Labile fractions also exhibited poor positive correlations for most of the metals, but for Cd, Co and Cr concentrations were significant ($p < 0.05$). Negative correlation was recorded between Cd vs Cr ($r = -0.78$) while positive correlation were recorded between Cd vs Ni (r = 0. 82); Co vs Fe (r = 0.59); Co vs Pb (r = 0.59) and Cr vs Mn (r = 0.63) (Table 5).

Multivariate statistics particularly factor analysis had enabled grouping of variables (heavy metals in this case) into a number of factors that exhibit a common behavior. In this way, the number of variables under investigation was reduced and interelement associations might be assessed in detail. Davis (1986) described effectively the method's principles, whilst numerous investigations benefited from its use (Nath *et al.*, 1989; Hodkinson and Cronan, 1991). R-mode factor analysis with varimax rotation was applied to the heavy metal concentrations in sediment and four-factor model explaining 90.23% and 87.88% of the total variance that were adopted for total and labile fractions, respectively (Table 6).

Factor 1 for total fraction accounts for 36.25% of the total data variance and shows a bipolar character. High positive loadings concern Cr, Fe, Mn and partly Co. These elements are known to be associated to hydrothermal processes, thus will be considered "hydrothermal factors". Hydrothermal fluids may have been responsible for the accumulation of metal oxides. In this four factors model, iron and Co are also represented partly in factors 2, 3 and 4; and manganese and chromium are presented partly in factor 3. These being controlled primarily by diagenetic re-mobilisation from sapropel layers. The allochthonous detrital phase is opposed to the autochthonous biogenous phase, which is represented by Cd that showed negative loadings.

Factor 2 for total fraction accounts for 20.96% of the data variance and showed high loadings for three metals namely Pb, Zn and partly Co while Fe. Co and Fe are associated to hydrothermal processes, thus will be partly named "hydrothermal factors". The absence of Mn participation in this factor is striking, while Zn is associated to sapropelic factor. Pb is incorporated into terrigenous alumino-silicates and, therefore, Pb can be associated to "terrigenous alumino-silicate factor", further corresponding to the "mud lithological unit".

Factore 3 accounted for 17.57% of the total data variance (Table 6) and showed high loadings for Ni and partly Co, Cr and Mn. These elements are associated to hydrothermal processes, thus will be named "hydrothermal factor".

Factor 4 accounted for 15.45% of the total variance and showed high loadings for Cu and partly Fe and Zn. Cu and Fe are associated to hydrothermal processes.

Factor 1 for labile fraction accounts for 26.77% of the total data variance and showed a bipolar character. High positive loadings concerned Cd and Ni and partly Co. These elements are associated to hydrothermal processes, thus will be named "hydrothermal factor". Cr is represented by partly negative loadings.

Factor 2 for labile fraction accounts for 23.24% of the total data variance and showed a high positive loadings concerning Co, Fe and Pb. Factor 3 showed high positive loadings concerning Cr, Mn and partly Co, which are associated to hydrothermal processes, and could be named "hydrothermal factor". Factor 4 showed a bipolar character and high positive loadings concerning Cu and Zn.

Human health risk due to exposure to contaminated sediments

The ingestion of sediment (Table 7), dermal contact with contaminated sediment (Table 8) and lifetime daily exposure (Table 9) were calculated for the studied locations of Lake Burullus for assessment of the human health risk, depending on the calculation made by Albering *et al.* (1999).

Ingestion of contaminated sediment (ICS) (mg kg^{-1} day^{-1})

$$= (CS \times IRS \times EF \times AF) \div BW$$

Dermal contact with contaminated sediment (DCCS) (mg kg^{-1} day^{-1})

$$= (CS \times SAS \times AD \times ASS \times Mf \times EDS \times EF \times AF) \div BW$$

Calculated lifetime daily exposure (CLTDE) (mg kg^{-1} day^{-1})

$$= [(6 \times TEL_{child}) \div 70] + [(64 \times TEL_{adult}) \div 7]$$

Hazard index = CLTDE ÷ tolerable daily intake (TDI)

Where CS = concentration of the heavy metal contaminant in sediment (mg kg^{-1}); IRS = ingestion rate of contaminated sediment (0.001 and 0.00035 kg dry weight/day for child and adult, respectively); EF = exposure frequency (30 for both child and adult); AF = absorption factor (1 for both child and adult) and BW = Body weight (15 and 70 kg for child and adult, respectively); SAS = Dermal surface area for sediment exposure (0.17 and 0.28 m^2 for child and adult, respectively); AD = Dermal adherence rate for sediment (0.51 and 3.75 mg cm^{-2} for child and adult, respectively); ASS = Dermal absorption rate (0.01 and 0.005 liter hr^{-1} for child and adult, respectively); MF = Matrix factor (0.15 the for both child and adult); EDS = Exposure duration to sediment (8 hr day^{-1} for both child and adult); EF = Exposure frequency (30 days $year^{-1}$ for both child and adult); TEL = total exposure levels; TDIs = tolerable daily intakes for heavy metals (Bockting *et al.*, 1996).

The concentrations of heavy metals recorded for sediments of Lake Burullus were high for all studied metals, which gave the ingestion of sediments (IS) for Fe and Mn in very high values (Table 7). Fe contamination in sediment showed IS between 25.51 to 91.74 and 1.91 to 6.88 mg kg^{-1} day^{-1} for child and adult, respectively. Mn contamination in sediment showed IS between 2.62 to 8.01 and 0.20 to 0.60 mg kg^{-1} day^{-1} for child and adult, respectively. The other metals exhibited high values but less than 1 mg kg^{-1} day^{-1} for both child and adult. Also, dermal contact with contaminated sediment (DCCS) exhibited high values for Fe and Mn (Table 8). DCCS for Fe ranged from 26.54 to 95.45 and 34.44 to 123.85 mg kg^{-1} day^{-1} for child and adult, respectively. Mn showed DCCS values from 2.73 to 7.52 and 3.54 to 9.75 mg kg^{-1} day^{-1} for child and adult, respectively. The other heavy metals in sediments of Lake Burullus recorded high values of DCCS but still less than 1 mg kg^{-1} day^{-1}. These high values led to high-calculated lifetime daily exposure (CLTDE) values, and therefore gave high hazard index values for all the studied sediments (Table 9). The results of these calculations indicate that sediment contamination by Pb, Cu, Mn, Cd and Zn in Lake Burullus may present a health hazard if the risks are calculated based on the standard exposure model. Background exposures to Cd, Cu, Pd and Zn have been estimated to be approximately 0.26, 21, 0.46, and 190 µg kg^{-1} day^{-1}, respectively (Albering *et al.*, 1999). The hazard index coming from contaminated sediment showed an existence of risk from exposure to Lake Burullus. However, studying the contaminated fish and water are necessary to reveal the exact hazard index for the Lake.

CONCLUSION

This study showed that heavy metal concentrations in the sediments of Lake Burullus were higher than the ERL but lower than the ERM values for all the studied metals at most of the examined studied locations. The calculations of risk assessment showed a possible health risk due to exposure to the contaminated sediment for long time.

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Table 1. Heavy metal concentrations (mg kg^{-1}) in total fraction for sediment of Lake Burullus.

Site No.	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	MPI
1	8.28	48.08	75.27	82.45	34112.5	4008.03	76.72	51.91	81.62	168.55
2	9.39	35.05	50.81	167.10	33830.9	1676.52	68.83	56.76	80.68	154.43
3	11.51	36.47	52.86	113.54	21119.2	1744.30	80.56	72.18	68.07	252.57
4	9.21	38.03	57.88	72.84	19230.7	1657.85	81.67	57.74	57.58	132.73
5	12.34	38.25	54.05	32.27	12755.7	1311.52	82.14	51.62	63.81	115.74
6	8.77	39.11	61.65	161.41	16986.3	1753.70	74.99	46.18	62.41	140.96
7	10.23	42.78	59.94	141.34	17697.0	1554.80	75.84	51.32	87.58	148.34
8	7.40	44.19	72.60	117.34	33107.5	2434.96	72.31	46.39	63.04	153.56
9	9.21	49.91	57.88	125.74	27725.3	1404.33	70.01	76.98	141.37	166.67
10	10.57	45.16	59.94	71.11	15140.8	1604.95	64.17	70.57	44.83	129.22
11	8.54	76.90	81.98	158.39	45869.7	3612.04	115.69	80.35	111.57	224.79
ERL	1.20	NA	81.00	34.00	NA	NA	20.90	46.70	150.00	NA
ERM	9.60	NA	370.00	270.00	NA	NA	51.60	218.00	410.00	NA
Mean	**9.58**	**44.90**	**62.26**	**113.05**	**25234.15**	**2069.36**	**78.45**	**60.18**	**78.41**	**162.51**
Median	**9.21**	**42.78**	**59.94**	**117.34**	**21119.2**	**1676.52**	**75.84**	**56.76**	**68.07**	**153.56**
STDEV	**1.46**	**11.65**	**10.01**	**43.74**	**10402.6**	**910.93**	**13.57**	**12.51**	**27.45**	**41.28**

NA = not available; The incidence of biological effects increased to 20% to 30% for most trace metals when concentrations exceeded ERL values but lower than the ERM values. When concentrations exceeded the ERM values, the incidence of adverse effects increased to 60% to 90%.

Table 2. Heavy metal concentrations (mg kg^{-1}) in labile fraction for sediment of Lake Burullus.

Site No.	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	MPI
1	5.67	31.63	48.15	57.71	5713.1	3588.02	53.38	42.69	51.63	102.06
2	7.02	26.37	19.66	90.71	5122.4	1271.85	60.10	50.84	40.99	86.44
3	6.30	30.39	29.36	67.75	6074.0	1353.75	53.87	63.79	58.78	95.04
4	6.36	29.58	38.58	47.21	5132.3	1404.33	58.99	49.90	37.01	86.43
5	8.33	30.97	23.57	28.25	2303.2	1143.73	66.52	41.80	43.25	72.36
6	6.16	35.81	34.26	109.75	4108.8	1360.25	57.13	38.66	54.03	93.63
7	7.97	34.70	15.09	77.23	3490.1	1391.40	59.63	46.83	67.97	87.38
8	5.05	31.32	40.85	61.41	6543.2	1949.55	48.04	31.70	38.05	87.26
9	7.37	42.03	16.25	83.49	8996.7	1277.20	63.05	63.03	84.69	105.54
10	7.01	37.58	26.14	37.02	4897.0	1189.44	50.73	60.86	30.53	80.37
11	7.96	59.15	28.94	71.49	8536.4	2808.67	68.06	69.85	50.42	121.09
Mean	**6.84**	**35.41**	**29.17**	**66.55**	**5537.93**	**1703.47**	**58.14**	**50.90**	**50.67**	**92.51**
Median	**7.01**	**31.63**	**28.94**	**67.75**	**5132.30**	**1360.25**	**58.99**	**49.90**	**50.42**	**87.38**
STDEV	**1.03**	**8.97**	**10.52**	**23.86**	**1993.23**	**787.78**	**6.31**	**12.07**	**15.60**	**13.29**

Table 3. Percentage of heavy metal concentrations in labile fraction relative to total fraction in Lake Burullus.

Site No.	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
1	68.53	65.79	63.96	69.99	16.75	89.52	69.58	82.23	63.26
2	74.85	75.23	38.69	54.28	15.14	75.86	87.32	89.56	50.80
3	54.71	83.33	55.55	59.68	28.76	77.61	66.87	88.38	86.35
4	69.14	77.78	66.67	64.81	26.69	84.71	72.22	86.42	64.27
5	67.48	80.98	43.60	87.54	18.06	87.21	80.98	80.98	67.77
6	70.33	91.57	55.57	67.99	24.19	77.56	76.19	83.72	86.57
7	77.87	81.12	25.17	54.64	19.72	89.49	78.62	91.26	77.60
8	68.34	70.87	56.28	52.34	19.76	80.06	66.44	68.34	60.36
9	80.05	84.21	28.07	66.40	32.45	90.95	90.06	81.87	59.91
10	66.30	83.21	43.61	52.06	32.34	74.11	79.05	86.24	68.11
11	93.15	76.92	35.30	45.14	18.61	77.76	58.83	86.94	45.19

Table 4. Spearman (Non-Paramatic) Rank Order Correlations for heavy metal in total fraction in lake Burullus sediment.

	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Cd	r = 1								
	p = 0.00								
Co	r = –0.38	r = 1							
	p = 0.25	p = 0.00							
Cr	**r = –0.68**	**r = 0.80**	r = 1						
	p = 0.02	**p = 0.003**	p = 0.00						
Cu	r = –0.47	r = 0.26	r = 0.16	r = 1					
	p = 0.14	p = 0.43	p = 0.64	p = 0.00					
Fe	**r = –0.58**	**r = 0.69**	**r = 0.68**	r = 0.49	r = 1				
	p = 0.02	**p = 0.02**	**p = 0.02**	p = 0.12	p = 0.00				
Mn	r = –0.58	**r = 0.65**	**r = 0.88**	r = 0.12	**r = 0.75**	r = 1			
	p = 0.06	**p = 0.03**	**p = 0.00**	p = 0.71	**p = 0.008**	p = 0.00			
Ni	r = –0.09	**r = 0.76**	r = 0.57	r = 0.17	r = 0.51	r = 0.53	r = 1		
	p = 0.79	**p = 0.007**	p = 0.07	p = 0.61	p = 0.11	p = 0.09	p = 0.00		
Pb	r = 0.17	r = 0.56	r = 0.07	r = 0.10	r = 0.30	r = 0.07	r = 0.38	r = 1	
	p = 0.62	p = 0.07	p = 0.84	p = 0.76	p = 0.36	p = 0.84	p = 0.24	p = 0.00	
Zn	r = –0.24	r = 0.55	r = 0.22	r = 0.43	r = 0.53	r = 0.19	r = 0.31	r = 0.51	r = 1
	p= 0.48	p = 0.08	p = 0.51	p = 0.19	p = 0.09	p = 0.57	p = 0.36	p = 0.11	p = 0.00

Correlations are significant at $p < 0.05$

Table 5. Spearman (Non-Paramatic) Rank Order Correlations for heavy metal in labile fraction in lake Burullus sediment.

	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Cd	r = 1 p = 0.00								
Co	r = 0.41 p = 0.21	r = 1 p = 0.00							
Cr	**r = –0.78** **p = 0.005**	r = –0.16 p = 0.64	r = 1 p = 0.00						
Cu	r = –0.13 p = 0.70	r = 0.13 p = 0.69	r = –0.19 p = 0.57	r = 1 p = 0.00					
Fe	r = –0.15 p = 0.64	**r = 0.59** **p = 0.05**	r = 0.05 p = 0.87	r = 0.26 p = 0.44	r = 1 p = 0.00				
Mn	r = –0.30 p = 0.37	r = 0.34 p = 0.34	**r = 0.63** **p = 0.03**	r = –0.03 p = 0.92	r = 0.37 p = 0.26	r = 1 p = 0.00			
Ni	**r = 0.82** **p = 0.002**	r = 0.48 p = 0.14	r = –0.51 p = 0.11	r = 0.08 p = 0.81	r = 0.07 p = 0.85	r = –0.06 p = 0.85	r = 1 p = 0.00		
Pb	r = 0.46 p = 0.16	**r = 0.59** **p = 0.05**	r = –0.42 p = 0.20	r = –0.005 p = 0.99	r = 0.56 p = 0.07	r = –0.03 p = 0.92	r = 0.37 p = 0.26	r = 1 p = 0.00	
Zn	r = 0.26 p = 0.43	r = 0.26 p = 0.43	r = –0.44 p = 0.17	r = 0.51 p = 0.13	r = 0.37 p = 0.26	r = –0.22 p = 0.95	r = 0.32 p = 0.31	r = 0.27 p = 0.41	r = 1 p = 0.00

Correlations are significant at $p < 0.05$

Table 6. Varimax-rotated factor loadings for four factors obtained for muddy sediments of Lake Burullus. Data were corrected prior to statistical analysis ($n = 99$).

Variable	Total fraction				Labile fraction			
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 1	Factor 2	Factor 3	Factor 4
Cd	–0.83	0.05	0.2	–0.43	**0.92**	0.13	–0.34	–0.07
Co	**0.57**	**0.52**	**0.57**	0.01	0.48	**0.70**	0.33	0.12
Cr	**0.90**	0.05	0.37	–0.02	–0.55	–0.15	**0.74**	–0.25
Cu	0.12	0.14	0.08	**0.96**	–0.08	0.01	–0.01	**0.91**
Fe	**0.73**	0.36	0.22	0.38	–0.15	**0.85**	0.26	0.31
Mn	**0.88**	0.04	0.34	–0.04	–0.04	0.18	**0.93**	–0.003
Ni	0.27	0.21	**0.91**	0.08	**0.92**	0.12	0.002	0.15
Pb	–0.09	**0.87**	0.31	–0.08	0.28	**0.87**	–0.24	–0.04
Zn	0.2	**0.81**	–0.01	0.36	0.26	0.24	–0.11	**0.79**
Variance (%)	36.25	20.96	17.57	15.45	26.77	23.24	19.64	18.24
CV (%)	36.25	57.22	74.79	90.23	26.77	50.01	69.64	87.88

CV: Cumulative Variance; Bold numbers indicate positive correlation, whereas underlined values indicate negative correlation. Extraction method: Principal component analysis; Rotation method: Varimax with Kaiser Normalization; Marked loadings are > 0.70.

Table 7. Calculation of ingestion of sediment for child and adult (mg kg^{-1} day^{-1}) in lake Burullus.

Site No.		Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
1	Child	0.017	0.096	0.151	0.165	68.225	8.016	0.153	0.104	0.163
	Adult	0.001	0.007	0.011	0.012	5.117	0.601	0.012	0.008	0.012
2	Child	0.019	0.070	0.102	0.334	67.662	3.353	0.138	0.114	0.161
	Adult	0.001	0.005	0.008	0.025	5.075	0.251	0.010	0.009	0.012
3	Child	0.023	0.073	0.106	0.227	42.238	3.489	0.161	0.144	0.136
	Adult	0.002	0.005	0.008	0.017	3.168	0.262	0.012	0.011	0.010
4	Child	0.018	0.076	0.116	0.146	38.461	3.316	0.163	0.115	0.115
	Adult	0.001	0.006	0.009	0.011	2.885	0.249	0.012	0.009	0.009
5	Child	0.025	0.076	0.108	0.065	25.511	2.623	0.164	0.103	0.128
	Adult	0.002	0.006	0.008	0.005	1.913	0.197	0.012	0.008	0.010
6	Child	0.018	0.078	0.123	0.323	33.973	3.507	0.150	0.092	0.125
	Adult	0.001	0.006	0.009	0.024	2.548	0.263	0.011	0.007	0.009
7	Child	0.020	0.086	0.120	0.283	35.394	3.110	0.152	0.103	0.175
	Adult	0.002	0.006	0.009	0.021	2.655	0.233	0.011	0.008	0.013
8	Child	0.015	0.088	0.145	0.235	66.215	4.870	0.145	0.093	0.126
	Adult	0.001	0.007	0.011	0.018	4.966	0.365	0.011	0.007	0.009
9	Child	0.018	0.100	0.116	0.251	55.451	2.809	0.140	0.154	0.283
	Adult	0.001	0.007	0.009	0.019	4.159	0.211	0.011	0.012	0.021
10	Child	0.021	0.090	0.120	0.142	30.282	3.210	0.128	0.141	0.090
	Adult	0.002	0.007	0.009	0.011	2.271	0.241	0.010	0.011	0.007
11	Child	0.017	0.154	0.164	0.317	91.739	7.224	0.231	0.161	0.223
	Adult	0.001	0.012	0.012	0.024	6.880	0.542	0.017	0.012	0.017

Table 8. Dermal contact with contaminated sediment for child and adult (mg kg^{-1} day^{-1}) in lake Burullus.

Site No.		Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
1	Child	0.02	0.10	0.16	0.17	70.98	8.34	0.16	0.11	0.17
	Adult	0.02	0.13	0.20	0.22	92.10	10.82	0.21	0.14	0.22
2	Child	0.02	0.07	0.11	0.35	70.40	3.49	0.14	0.12	0.17
	Adult	0.03	0.09	0.14	0.45	91.34	4.53	0.19	0.15	0.22
3	Child	0.02	0.08	0.11	0.24	43.94	3.63	0.17	0.15	0.14
	Adult	0.03	0.10	0.14	0.31	57.02	4.71	0.22	0.19	0.18
4	Child	0.02	0.08	0.12	0.15	40.02	3.45	0.17	0.12	0.12
	Adult	0.02	0.10	0.16	0.20	51.92	4.48	0.22	0.16	0.16
5	Child	0.03	0.08	0.11	0.07	26.54	2.73	0.17	0.11	0.13
	Adult	0.03	0.10	0.15	0.09	34.44	3.54	0.22	0.14	0.17
6	Child	0.02	0.08	0.13	0.34	35.35	3.65	0.16	0.10	0.13
	Adult	0.02	0.11	0.17	0.44	45.86	4.73	0.20	0.12	0.17
7	Child	0.02	0.09	0.12	0.29	36.82	3.24	0.16	0.11	0.18
	Adult	0.03	0.12	0.16	0.38	47.78	4.20	0.20	0.14	0.24
8	Child	0.02	0.09	0.15	0.24	68.89	5.07	0.15	0.10	0.13
	Adult	0.02	0.12	0.20	0.32	89.39	6.57	0.20	0.13	0.17
9	Child	0.02	0.10	0.12	0.26	57.69	2.92	0.15	0.16	0.29
	Adult	0.02	0.13	0.16	0.34	74.86	3.79	0.19	0.21	0.38
10	Child	0.02	0.09	0.12	0.15	31:50	3.34	0.13	0.15	0.09
	Adult	0.03	0.12	0.16	0.19	40.88	4.33	0.17	0.19	0.12
11	Child	0.02	0.16	0.17	0.33	95.45	7.52	0.24	0.17	0.23
	Adult	0.02	0.21	0.22	0.43	123.85	9.75	0.31	0.22	0.30

Table 9. Calculated lifetime daily exposure (mg kg^{-1} day^{-1}) to sediment of lake Burullus.

Site No.	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
1	0.22	1.27	1.99	2.18	900.81	105.84	2.03	1.37	2.16
2	0.25	0.93	1.34	4.41	893.37	44.27	1.82	1.50	2.13
3	0.30	0.96	1.40	3.00	557.69	46.06	2.13	1.91	1.80
4	0.24	1.00	1.53	1.92	507.82	43.78	2.16	1.52	1.52
5	0.33	1.01	1.43	0.85	336.84	34.63	2.17	1.36	1.69
6	0.23	1.03	1.63	4.26	448.56	46.31	1.98	1.22	1.65
7	0.27	1.13	1.58	3.73	467.32	41.06	2.00	1.36	2.31
8	0.20	1.17	1.92	3.10	874.27	64.30	1.91	1.22	1.66
9	0.24	1.32	1.53	3.32	732.14	37.08	1.85	2.03	3.73
10	0.28	1.19	1.58	1.88	399.82	42.38	1.69	1.86	1.18
11	0.23	2.03	2.16	4.18	1211.28	95.38	3.06	2.12	2.95

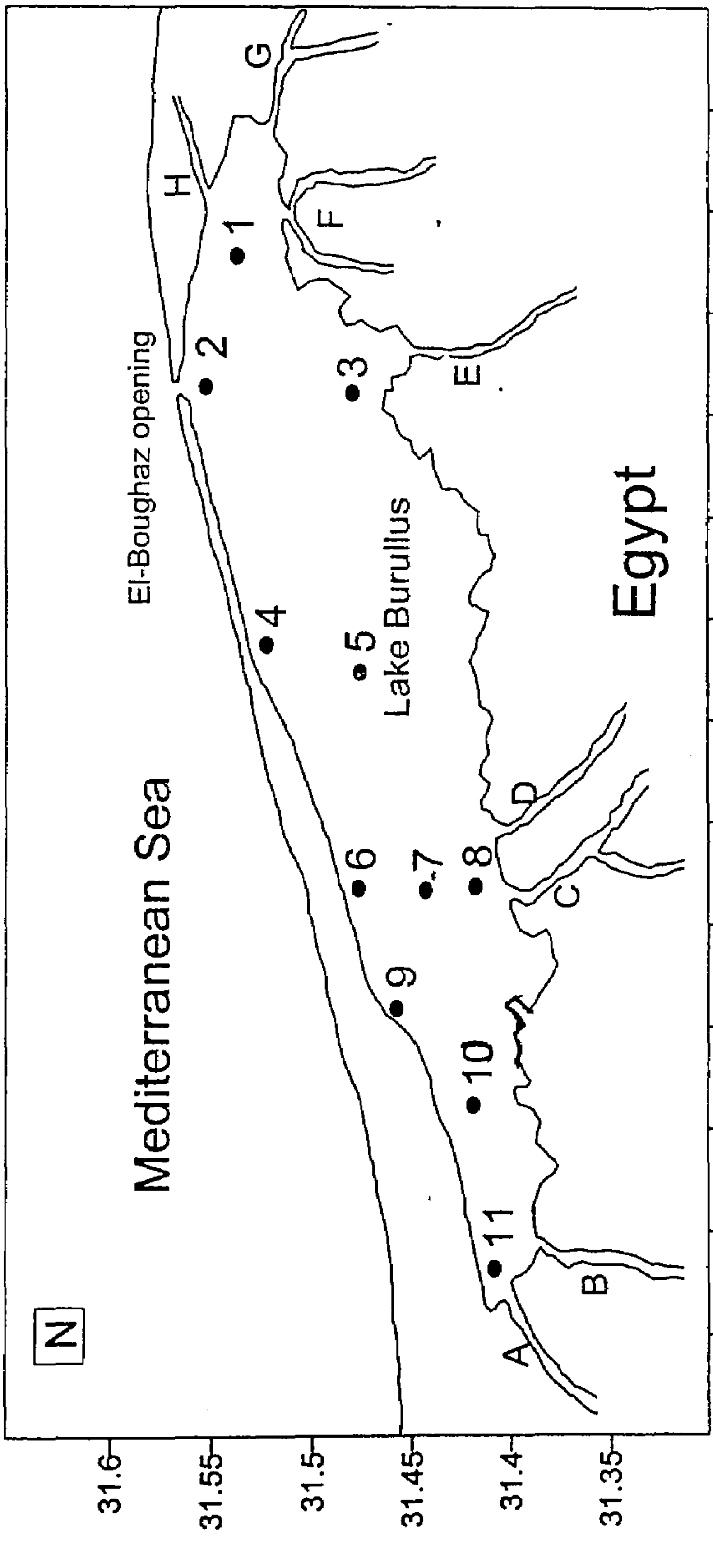

Figure 1. Sampling sites and drains connected to Lake Burulus.
A: Brimbal Canal; B: Drain 11; C: Drain 9: D: Drain 8; E: Drain 7; F: Nasser Drain; G: El-Gharbia Drain; H: El-Burullus Drain.