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Full Length Research Paper

Heavy metal speciation and their accumulation in sediments of Lake Burullus, Egypt

Mamdouh S. Masoud[1], Mamdouh A. Fahmy[2], Alaa E. Ali[3*] and Essam A. Mohamed[3]

[1]Chemistry Department, Faculty of Science, Alexandria University, Alexandria, Egypt.
[2]Chemistry Laboratory, Marine Environment Division, National Institute of Oceanography and Fisheries, Alexandria, Egypt.
[3]Chemistry Department, Faculty of Science, Damnhour University, Damnhour, Egypt.

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Several sediment samples in Lake Burullus have been affected by the discharges of heavy metals through different drains. The study aimed to analyze the chemical speciation of these metals. In particular, the chemical forms of Cd, Cu, Fe, Mn, Pb and Zn in sediments collected in spring season were studied using a sequential chemical extraction method. In general, all the elements recorded highest concentrations in the area near the discharge point. The data indicated that, the sediments were under a wide variety of environmental conditions ranging from oxic to fully anoxic conditions. Owing a wide variety of grain sizes and organic matter, these metals showed the order of abundance: Fe > Mn > Zn > Cu > Cd > Pb. Significant correlations between iron with clay, organic carbon and manganese concentrations were calculated as (r=0.685, 0.581 and 0.610, P= 0.05), respectively. This gives an idea about association of iron and manganese as main compositions of clays. In the mean time, it showed insignificant relation with total carbonate and all phosphorus forms. The metal speciation characterizes the degree to which they are potentially labile or bioavailability. It gives different fraction ratios depending on binding and sediment origin.

Key words: Heavy metals, chemical speciation, sediments, Burullus, Lake.

INTRODUCTION

Lake Burullus is one of the Nile delta lakes located between the two main Delta promontories Rosetta and Damietta. It lies on the eastern side of Rosetta branch of the Nile. It occupies a central position along the Mediterranean coast of the Nile. It lies between longitude 30° 30` and 31° 10`E, and latitude 31° 21` and 31° 35` N.

It has an irregular elongated shape and connected to the sea through a narrow (50 m wide) passage called Al-Burg inlet or Boughaz Al-Burullus, Figure (1). The lagoon is separated from the sea by a long curving sand barrier. The length of the lake is about 47 km, and the width varied between 6 and 16 km, with an average of about 11 km. The depth of the lake ranges between 0.42 and 2.07 m. The eastern sector of the lake is the shallowest, showing an average depth of 0.8 m.

The present area of Lake Burullus is about 420 km^2 of which 370 km^2 is open water. Former estimates of the area are 588 km^2 in 1913, 574 km^2 in 1956 and 462 km^2 in 1974 (Meininger and Atta, 1994). It seems that during the last 10 years there has been a reduction in the lake area by 30%. This decrease is due to continuous land reclamation projects along the southern and eastern shores of the lake.

Burullus Lagoon receives 2.46 × 10^9 m^3 y^{-1} of brackish water through drains (Ahmed et al., 2001). The drains are the following, El Burullus, Nasser in the eastern side of the lake, Drain 7, 8, 9 and 11 in the southern side of the lake, Brimbal Canal in the western extremity of the lake receives fresh water directly from Rossetta branch during the flood periods, Figure (1) and Gharbia drain.

Accordingly, we aimed to clarify the conditions in which heavy metals can be released to water and affect on the

*Corresponding author. E-mail: dralaae@yahoo.com.

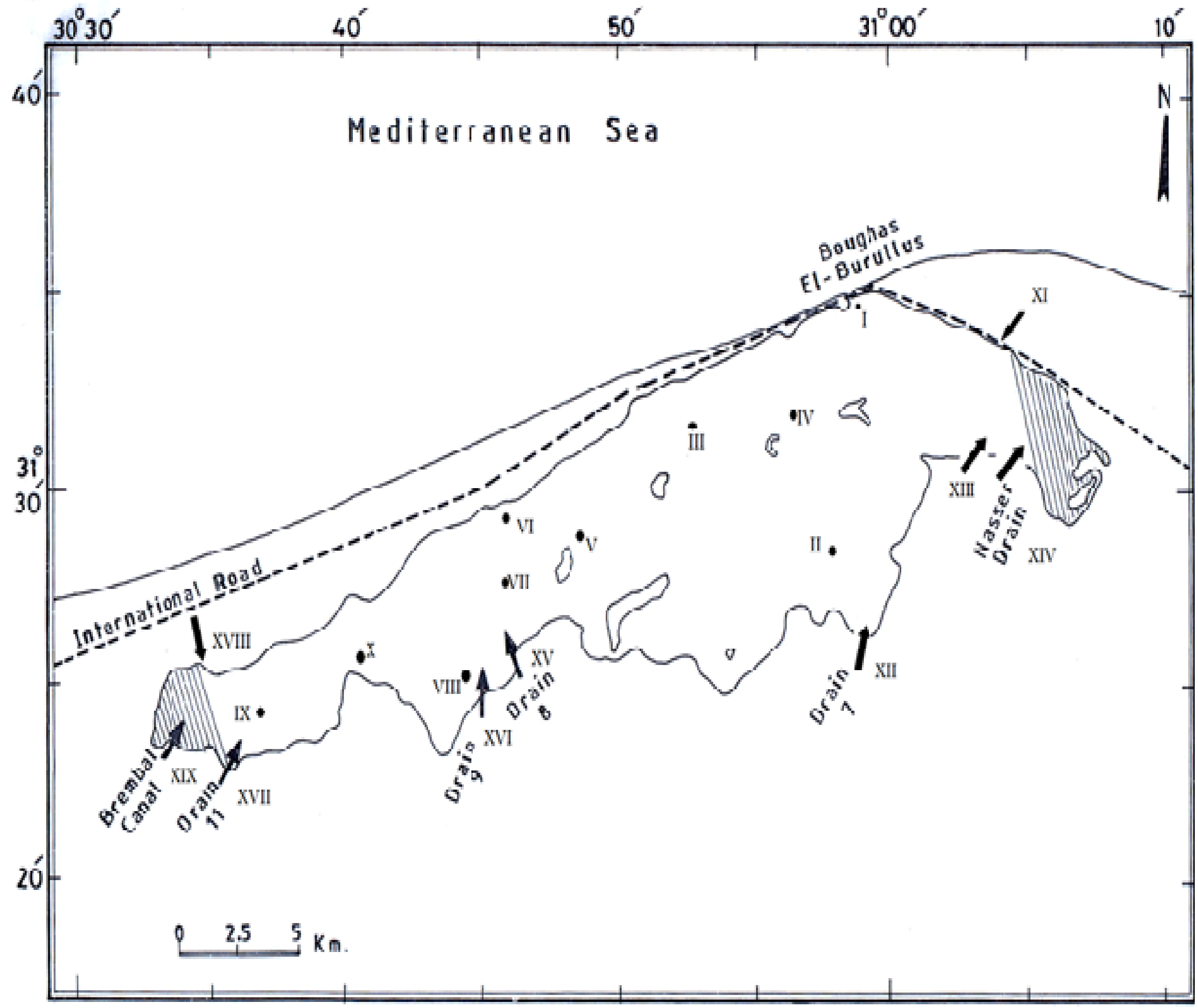

Figure 1. Map of Sampling Locations at Lake Burullus, Egypt.

biological lake life.

MATERIALS AND METHODS

Sediments sampling

During the five seasons at least two surface grab sediment samples were collected from nineteen selected locations of Lake Burullus and its drains using a Van-Veen grab sampler.

The stations were selected on the map to cover the whole area of the lake and drain waters. We reach the stations using Global Positioning System (GPS). The sediment samples were then preserved in plastic bags and kept frozen until further analyses.

Preparation of samples

Grain size analysis

The sediment samples were subjected to grain size analysis according to the method described by Folk (1974). The different fractions of sediment samples were sieved and then subjected to pipette analysis to separate the smaller mud fractions.

Water content

For determination of water content 20 g of freshly wet collected sediment samples in a silica crucible were dried overnight at 105°C in an oven. The samples were reweighed to a constant weight and the percentages of water contents were calculated.

Organic carbon (OC)

The OC was determined by weighing 0.3 g of powdered dry sediment samples (Gaudette and Flight, 1974).

Total carbonate

Total carbonate in sediment samples was analyzed by titration

Table 1. Grain size analysis data and Eh (mv) for the sediments of Lake Burullus waters and drains.

Stations	clay	silt (%)	sand	Eh mv	Sediment type (Folk, 1974)	Sorting Coefficient (Phi)	Sorting Type
I	37.83	30.03	32.14	56	Sandy mud	3.83	Very poorly sorted
II	37.97	46.03	16	40	Sandy mud	3.69	Very poorly sorted
III	39.47	22.94	37.59	33	Sandy mud	4.47	Extremely poorly sorted
IV	36.32	37.1	26.58	26	Sandy mud	3.58	Very poorly sorted
V	21.3	49.12	29.58	14	Sandy silt	3.41	Very poorly sorted
VI	32.5	61.07	6.43	92	Muddy	3.28	Very poorly sorted
VII	31.84	30.68	37.48	158	Sandy mud	4.26	Extremely poorly sorted
VIII	21.3	49.12	29.58	124	Sandy silt	3.41	Very poorly sorted
IX	18.74	42.8	38.46	107	Sandy silt	3.45	Very poorly sorted
X	55.74	26.72	17.54	361	Sandy clay	4.11	Extremely poorly sorted
XI	56.33	28.73	14.94	304	Sandy mud	3.92	Very poorly sorted
XII	48.13	38.4	13.47	291	Sandy mud	4.47	Extremely poorly sorted
XIII	57.59	25.68	16.73	289	Sandy clay	3.74	Very poorly sorted
XIV	38.01	33.33	28.66	295	Sandy mud	3.88	Very poorly sorted
XV	53.47	38.68	7.85	168	Muddy	3.27	Very poorly sorted
XVI	36.74	32.4	30.86	81	Sandy mud	3.96	Very poorly sorted
XVII	61.79	37.52	0.69	369	Muddy	2.84	Very poorly sorted
XVIII	34.02	17.51	48.47	310	Sandy mud	3.96	Very poorly sorted
XIX	49.78	48.91	1.31	285	Muddy	2.92	Very poorly sorted

technique (Herrin et al., 1957; Black, 1965) where exactly 0.5 g of each sample was treated with an excess of 1 N HCl followed by back titration with standardized 1 N NaOH solution using phenolphthalein as an indicator.

Redox potential (Eh)

Eh measurements were performed immediately after collection of sediment samples.

Inorganic, organic and total phosphorous

Inorganic, organic and total phosphorous in the sediment samples were determined by the method described by Aspila et al. (1976). This method was applied using dilute acid to determine inorganic phosphate then other samples were ignited to determine total phosphorous. From the previous data we can calculate organic phosphate concentration.

Heavy metals determination (Fe, Mn, Cu, Zn, Pb and Cd)

Heavy metals in the sediment samples were determined using the method described by Oregioni and Aston (1984). 0.3 g of air dried and ground sediment samples were treated with 3 ml conc HNO_3; 2 ml conc $HClO_4$ and 1 ml conc HF in a tightly closed Teflon vials and digested on a hot plate at 180°C until complete digestion. The samples were heated to near dryness then 1 ml of 6 N HNO_3 was added and completed to 25 ml with DDW (MEDPOL, 1996). The analysis was performed using flame atomic absorption spectroscopy (Perkin Elmer, Model 2380).

RESULTS AND DISCUSSION

Sediment analysis

Grain size (Texture) analysis

The distribution of sediment composition depends on the equilibrium between gravity of sediments and water forces. It is one of the major controlling factors for the distribution of trace metals in the lake (El- Shabiny et al., 1996). The results of is easy to notice that most of the sediments of Lake Burrullus are rich in sand fraction.

Lake sediments contained appreciable amounts of tubeworm skeletons of some calcareous organisms, gastropod shell fragments and plant roots. As mentioned, the texture of lake sediments was less variable (mainly sandy), with some muddy sediments in some stations (Station VI, XV, XVII and XIX) as shown in Table (1). Obviously, these sediments were exposed more to the sea and current actions leading to such good sorting and dominance of the coarser sandy fraction. The dominance was sandy mud sediments in most stations.

Water content

The water content of Lake Burrullus sediments during winter 2004 to winter 2005 ranged from 45.8% in the sandy sediments of station II to 82.6% in the muddy

Table 2. The levels organic carbon (%), total carbonate (%), phosphorous forms (µg/g), OC: OP ratio and water content in the sediments of Lake Burullus basins and drains.

Stations	Organic carbon	Total carbonate	Inorganic phosphorous	organic phosphorous	Total phosphorous	OC:OP	Water content
	(%)			(µg/g)			(%)
I	1.33	4.74	512	94	606	141.49	58.20
II	1.97	44.46	486	146	632	134.93	45.80
III	1.37	38.21	351	972	1323	14.09	60.70
IV	2.5	28.57	485	155	640	161.29	52.60
V	1.12	52.12	390	83	474	134.94	69.10
VI	1.25	8.18	816	40	856	312.50	52.60
VII	1.07	30.57	430	83	513	128.92	46.30
VIII	1.17	31.48	496	115	611	101.74	63.10
IX	0.97	32.82	541	67	609	144.78	46.50
X	1.08	44.89	524	123	647	87.80	51.20
XI	1.52	28.65	469	140	609	108.57	76.50
XII	0.56	65.76	477	30	507	186.67	64.50
XIII	1.93	35.06	451	89	630	216.85	82.60
XIV	1.93	35.06	451	89	630	216.85	63.90
XV	0.68	10.92	690	70	760	97.14	73.80
XVI	1.59	34.26	500	153	653	103.92	58.80
XVII	2.33	3.24	902	219	1121	106.39	62.90
XVIII	1.65	1.96	415	25	440	660.00	76.10
XIX	3.26	23.19	817	291	1108	112.03	70.10

sediment of station XIV (Therah drain). Generally, the sandy sediments showed lower water content as compared with those of muddy sediment shown in Table (2).

Organic carbon (OC)

The concentration and distribution pattern of OC percentage in the surface sediments of Lake Burrullus are shown in Table (2). The OC content fluctuated from a minimum value (0.56%) at station XII (Drain 7) in the eastern drain part to a maximum (3.26%) in the muddy sediments at station XIX (Brinbal drain) in the western drain part. It also shows that, at stations where the OC percentage was low, it always tied with the coarser sediments, while that high OC was mostly combined with more fine sediments, reflecting the association of OC with the fine sediments (mud).

Carbonate

The concentrations of carbonate in the sediments, Table (2) were found between 1.96% at station XVIII (West Burullus drain) and 65.76% at station XII (Drain 7). The high value of carbonate was attributed principally to aquatic plants and phytoplankton applied to extract CO_2 and thus promote precipitation of carbonate with the increase of pH. Also, the high values could be due to a biogenic precipitation of organite by aquatic organisms building their calcareous shells (Aboul-Naga, 2000), and/or due to the calcium rich water where $CaCO_3$ is precipitated with the increase in pH values during photosynthesis.

The levels of carbonate in the grab sediments of the present study gave higher values due to the effect of increasing calcareous shells in the lake sediments.

Redox potential Eh (mv)

The Eh values in the lake sediment, fluctuated between 14 and 369 mv. From these one can notice that most of the sediments of Lake Burrullus had positive Eh values. Such finding reflects the presence of these sediments under oxidizing conditions. The increase in Eh may be in conjunction with increasing the most effective oxidants of organic matter.

Phosphorus (P)

Total phosphorus (TP): In the Lake sediments, TP ranged from a minimum of 440 ppm in the sandy mud sediments at station XVIII (West Burrullus Drain) to a

Table 3. Comparison between TP % obtained in the present study and previous studies from the surfacial sediments of Lake Burullus and some other Egyptian regions.

Area	Range	Mean	Sampling date	Reference
Lake Burrullus	0.044 – 0.132	0.07	2005	Present study
Rosetta EstuaryRiver Side	0.02-0.11	0.07		
Upstream	0.02-0.05	0.04	1978	Draz (1983)
Downstream	0.02-0.10	0.05		
Lake Naser	0.09-0.63	0.38	1994	Saad and Shata (1994)
Lake Edku	0.05-0.133	0.071	1987	Ibrahim (1994)
	0.09-0.18	0.14	1984	Hemaida (1988)
Lake Manzalah	0.02-0.10	0.06	1970	El-Wakeel and Wahby (1970)
	0.014-0.112	0.050	1996	Ibrahim (2003)
Lake Mariut	0.05-0.18	0.10	1970	El-Wakeel and Wahby (1970)
	0.115-0.313	0.22	1996	Abdallah (2003)
Mediterranean	0.0009-0.081	0.036	1996	Ibrahim (2003)
Abu-Kir Bay	0.044-0.076	0.057	1996	Faragallah (2004)

maximum of 1323 ppm in the sediments of station III (Ibsak).

Inorganic phosphorus (IP): The IP values of fluctuated between 351 ppm in the sandy mud sediments at Station III and 902 ppm in the muddy sediments at Station XVII (Drain 11). This fraction has constituted > 50% of TP, except in the sandy mud sediments at Station III where it represented < 50% of TP.

Organic phosphorus (OP): Their concentrations were generally lower than those of IP, except those at Stations III, where it represents more than 50% of TP. Generally, TP showed better relationship with each of IP (r = 0.509) and OP (r= 0.776) whereas, insignificant relationship between IP and OP (r = -0.135) was observed. In the mean time, IP showed a good association with silt (r = 0.519). OP showed an insignificant relation with OC of the sediments (0.186). The comparison between TP in the present study and some other studies was shown in Table 3. The TP percentage in surfacial sediments of the present study showed noticeable higher concentrations compared with those of Draz (1983) for the same region, as well as for many of other neighboring regions Table 3. This implies the increasing rate of phosphorus precipitation in Lake Burrullus during the present time as compared with those of the others.

Organic carbon OC: Organic phosphorous OP (molar) ratio

The ratios OC: OP in the surfacial sediments of Lake Burrullus are listed in Table 4. They ranged from 14.1 in the sandy mud sediments of Station III to 660 at Station XVIII (West Burrullus drain). The rate of C and P regeneration in lake water, and thus C: P of the remaining organic matter varies considerably relative to one another. The rate of plankton growth and dissolved nutrient concentrations apparently play an important role in determining the C: P ratio of the living plankton (Adams, 1973). As a result of these and other factors, the C: P ratio of organic matter in sediments varies considerably.

Heavy metals in sediment samples

Pollution of the environment with toxic metals has attracted considerable public attention over the past few decades. Heavy metals released into aquatic systems are generally bound to particulate matter, which eventually settle down and become incorporated into sediments. Surface sediment therefore is the most important reservoir or sink of metals and other pollutants in aquatic environments (Penga et al., 2008). Under favorable conditions, sediment can release pollutants causing detrimental effects to aquatic biota long after the initial input of pollution has ceased.

Table 4. Comparison between OC: OP % obtained in the present study and previous studies from the surfacial sediments of Lake Burullus and some other Egyptian regions.

Areas	OC : O P	Samling dates	References
Burullus (range) Average	(14.1-660) (166.9:1)	2005	Present study
Rosetta SS	(151 : 1)		El-Sabaruti et al. (1990)
Abu-Kir Bay	247 : 1 173 : 1	 1996	El-Sabaruti et al. (1990) Faragallah (2004)
Lake El Burrullus	176 : 1		El-Sabaruti et al. (1990)
Lake Manzalah	674 : 1	1996	Ibrahim (2003)
Lake Mariut	349 : 1	1996	Abdallah (2003)
Damietta Sea side	205 : 1		El-Sabaruti et al.(1990)
Mediterranean	130 : 1	1996	Ibrahim (2003)

Heavy metal and organic pollutants in sediments have been investigated by researchers, they regarded as a potential menace to ecosystems (Weng et al., 2008).

Sediment analyses play an important role in assessments of pollution status of environment. They provide a temporally integrated indication of the aquatic environmental condition and act as a major reservoir for metals (Caccia et al., 2003), though some sediment can also act as a source of contaminants. One advantage of the use of sediment analysis, rather than water analysis, for evaluating the degree of contamination in aquatic medium, it gives a stable image over time compared with the huge temporal variability in the levels of contaminants in water. Furthermore, concentrations of toxic elements are usually higher in sediment and therefore less possibility of contamination of samples during handling and processing.

Darrag (1984) in his study on trace metals concentrations in the sediments of Lake Burullus pointed out that the concentrations of these elements tended generally to decrease from west to north-east. On the other hand some areas are far from the drain water inflow and others are sheltered by islets therefore their water are partially stagnant. Natural reservoirs such as lagoons and coastal lakes act as containment basins for pollutants.

Anthropogenic contamination can thus be traced from the level of excess metal concentration in sediments whose initial natural composition is known.

In the present study, the concentrations of heavy metals (Fe, Mn, Cu, Zn, Pb and Cd) in the sediments of Lake Burullus are listed in Table 5. They indicated that despite sediments are present under a wide variety of environmental conditions, ranging from oxic to fully anoxic conditions, besides a wide variety of grain size, and OC contents, these metals showed same order of abundance: Fe >Mn > Zn > Cu > Cd >Pb.

Iron

It is a matter of fact that the drain water transplants respectful concentrations of iron to Lake Burullus. Precipitation of iron may be undertaken by bacteria in two ways. In the first way, only the organic matter associated with iron is metabolized, ferric hydroxide being left over is precipitated. Secondly iron is actually involved in the metabolism of bacteria which can derive energy for the synthesis of organic compounds by the oxidation of ferrous salts such as $FeCO_3$ of $Fe(HCO_3)_2$ (Cole, 1979). In the present study, its concentrations ranged from 5.37 mg/g in the sandy mud sediments of Station IX at the western part of the lake to 10.1 mg/g in the muddy sediments at both Stations XV and XIX of the Lake drains, giving an overall mean of 7.99 mg/g. The sediment content of iron is mostly controlled by two factors, namely the distance from the outfall and the nature of sediment. In this concern trace metal concentrations, sediments were found to decrease with respect to the distance away from outfall, indicating a lower rate of deposition of suspended particulates away from the discharged area. The sandy nature of the lake sediment may also be the reason of their relatively lower iron content (Shakweer et al, 2004).

The horizontal distribution of iron in the lake sediments showed higher concentrations in the western area in comparison with its concentrations in either the middle or eastern areas. The clay content in the sediments of the lake plays an important role in the distribution pattern of iron content in the bottom sediments. The horizontal isolines distribution of iron in sediments is represented in Figure 2. It increased to the middle giving high concentration center.

Table 5. The levels heavy metals (µg/g) in the sediments of Lake Burullus basins and drains.

Stations	Fe	Mn	Cu	Zn	Cd	Pb
	(µg/g)					
I	8000	904.70	52.60	481.60	5.84	6.79
II	8500	1220.00	54.20	482.80	8.99	1.04
III	6900	981.40	71.50	209.00	11.22	1.82
IV	9500	1020.00	63.80	179.90	10.45	6.31
V	6800	1240.00	109.50	218.10	14.96	6.26
VI	6173	947.10	73.90	265.50	8.13	3.48
VII	5568	1134.90	64.70	458.60	15.21	9.33
VIII	7800	824.60	84.00	215.00	11.56	3.67
IX	5370	921.10	102.10	252.70	9.42	2.64
X	8300	1140.00	69.60	244.40	9.43	2.66
XI	8400	1630.00	99.10	267.80	5.91	4.75
XII	7300	1120.00	90.80	163.00	9.43	3.47
XIII	9700	1496.30	99.20	255.50	9.62	1.59
XIV	8800	1590.00	129.40	299.70	12.63	8.32
XV	10100	1330.30	121.70	183.90	16.42	1.31
XVI	6819	882.50	121.90	234.60	7.19	4.67
XVII	9657	1782.80	64.80	210.00	11.95	4.26
XVIII	8000	1790.00	55.30	273.70	10.01	3.21
XIX	10100	2030.00	50.30	194.70	9.26	3.09

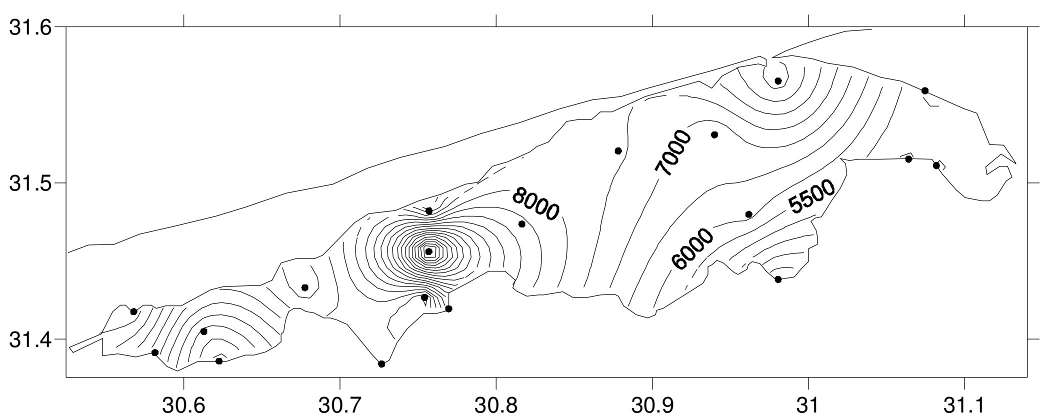

Figure 2. Horizontal distribution of the iron (µg/l) in Lake Burullus sediments during spring 2005.

Significant correlations between iron with each clay, organic carbon and manganese concentrations were observed (r=0.685, 0.581 and 0.610, respectively). These may give an idea about association of iron and manganese as main compositions of clays. In the mean time it showed insignificant relation with each total carbonate and all phosphorus forms Table 5.

Manganese

Their values ranged from 0.825 mg/g in the sediments of station VIII to 2.03 mg/g in the sediments of Station XIX with an overall mean 1.262 mg/g. Its fluctuation was relatively wider than that noticed for Fe. The horizontal isolines distribution of manganese in sediment is represented in Figure 3. It increased to the middle giving high concentration center.

Copper

It is a matter of fact that drainage water is the main source of copper for Lake Burullus. The average concentrations of copper in the sediments of Lake Burullus during 2004 to 2005 are given in Table 5. They

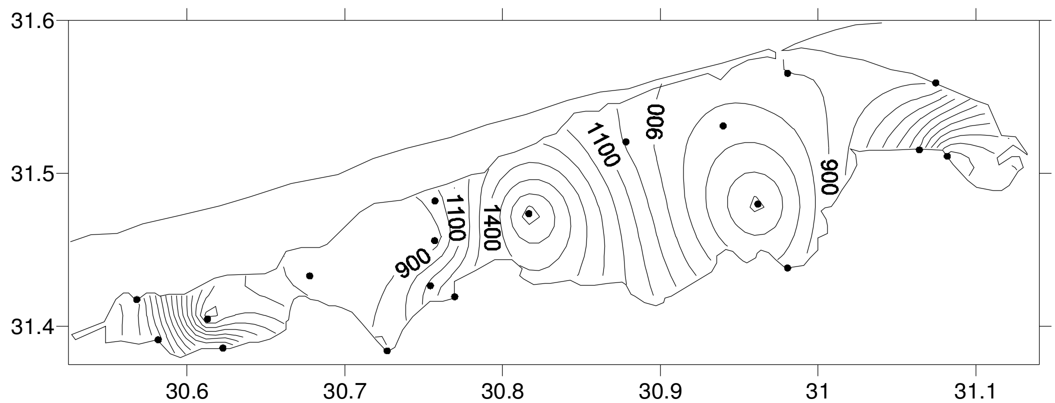

Figure 3. Horizontal distribution of the manganese (µg/l) in Lake Burullus sediments during spring 2005.

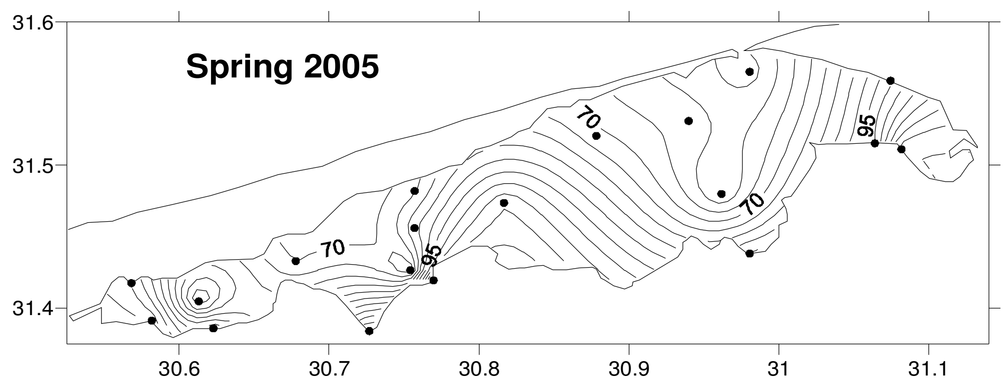

Figure 4. Horizontal distribution of the copper (µg/l) in Lake Burullus sediments during spring 2005.

demonstrated that, the concentration ranged from 52.60 ppm at Station I to 129.41 ppm at Station XIV with an overall mean of 83.08 ppm.

The horizontal isolines distribution of copper in sediment is represented in Figure 4. It increased to the middle giving high concentration center.

The higher concentrations found at the southern areas may be due to the increasing rate of copper precipitation with particles from the lake water (Shakweer et al., 2004).

Zinc

Although zinc is one of the most abundant toxic heavy metals, the oral toxicity in humans to most zinc compounds is relatively low (Helstead, 1974).

High concentrations of this metal in the marine environment may exist from the discharge of industrial wastes especially electroplating and synthetic fiber production.

It is a matter of fact that El-Gharbia drain which discharge its waste water directly at Lake Burullus plays a significant role in transplanting the wastes of many textile companies located at El-Mehalla El-Kobra. These wastes are believed to contain high concentrations of Zn compounds.

The concentrations of Zn in the sediments of Lake Burullus during the study season are listed in Table 5. They fluctuated between 179.89 ppm at Station II and 482.77ppm at Station IV, giving the general mean of 267.91 ppm. Higher concentrations were found in sediments at the eastern and middle areas of the lake.

These high concentrations may be attributed to the high concentrations of Zn in the fresh water discharged at the middle Drains 8 and 9.

The horizontal isolines distribution of zinc in sediment is represented in Figure 5. It increased to the north east direction forming two centers and another center appeared in the middle lake basin. Comparing the concentrations of Zn and Cu in the sediments of Lake Burullus with those in the sediments of other areas in Egypt it appears that this lake is still undisturbed with these elements in comparison with those in the other areas, but it tended to increase than those previous records.

However, high concentration of trace elements in the sediments can be considered as an indicator for the industrial activity around the aquatic environment where

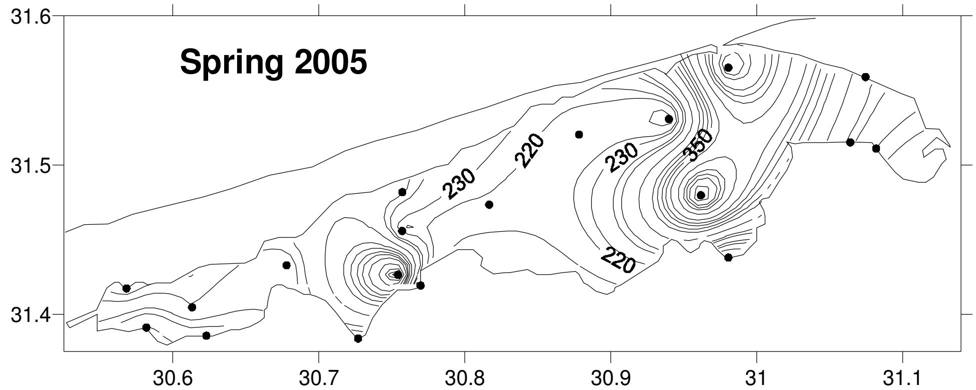

Figure 5. Horizontal distribution of the zinc (µg/l) in Lake Burullus sediments during spring 2005.

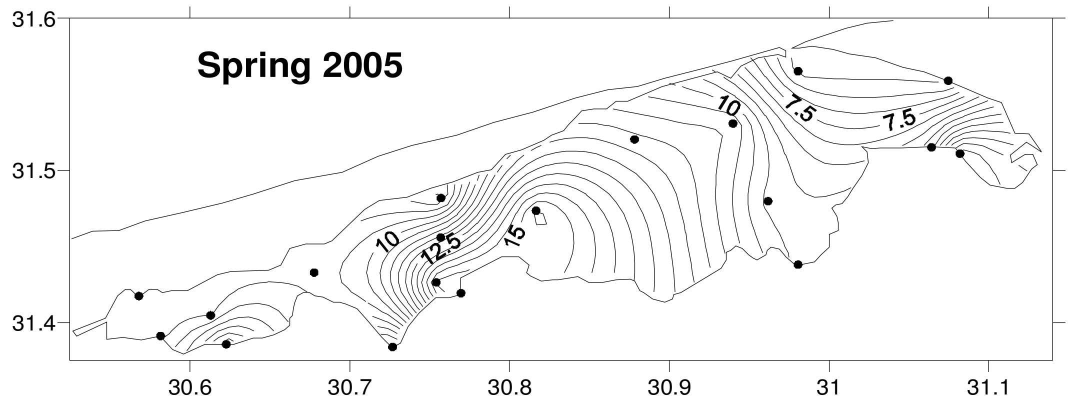

Figure 6. Horizontal distribution of the cadmium (µg/l) in Lake Burullus sediments during spring 2005.

industrial wastes are discharged.

Cadmium

It is a matter of fact that Cd is one of the black listed elements, it can be considered as one of the most dangerous elements on marine life and humans.

The concentrations of this element in the sediments of Lake Burrullus are given in Table 5 during the present study.

The horizontal isolines distribution of cadmium in sediment is represented in Figure 6. It increased to the middle giving high concentration center.

It can be pointed out that, the most polluted sediments with this elements located at the middle area of the lake. It ranged from 5.84 ppm in the sediments at Station I to 16.42 ppm at Station XV, giving a general mean of 10.40 ppm. It also showed no general trend in distribution of its concentrations along the Lake.

Lead

The extensive use of lead in historic time made it as one of the earliest known metal pollutants. In the present century it has increasing usage as an additive to petrol fuel for use in internal combustion engines and in making batteries. This rapid rise in the use of lead by man has resulted in large increase in the levels of lead prevailing in the environment. WHO (1987) reported that lead in the environment is strongly absorbed into sediment and soil particles reducing its availability to organisms. Uptake of lead from marine environment was found to exceed that of copper and cadmium. Many plants concentrate the uptake of lead in roots.

The average concentrations of Pb in the sediments of Lake Burrullus during the years 2004 and 2005 are given in Table 5.

It ranged from 1.04 ppm in the sediments at Station II to 9.33 ppm in the sediments of the Lake at Station VII, giving the general means of 14.14 ppm. It also showed no general trend in distribution of its concentrations along the Lake. The western area of Lake Burullus is the least polluted area of the lake with Pb which is considered as one of the black listed pollutants. The horizontal isolines distribution of lead in sediment is represented in Figure 7. It increased to the north east (Boughaz El-burg) giving high concentration center. It

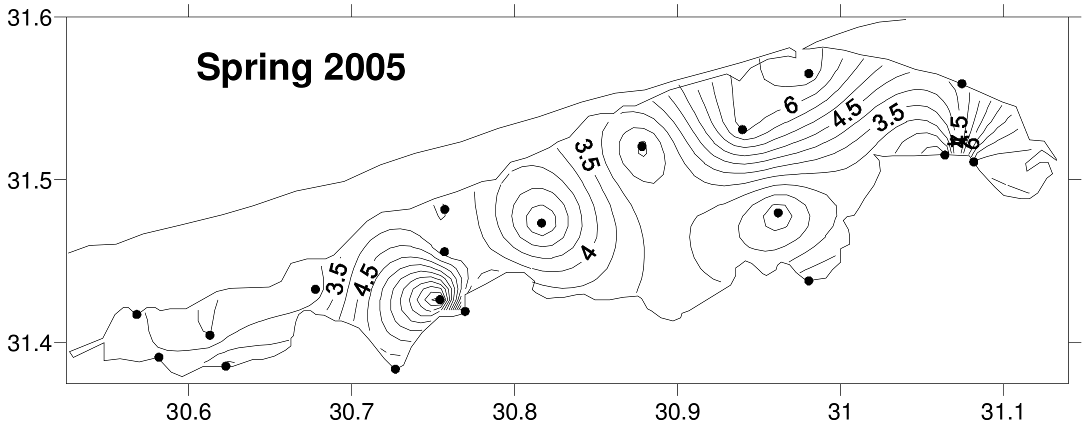

Figure 7. Horizontal distribution of the lead (µg/l) in Lake Burullus sediments during spring 2005.

also showed two high concentration centers in the middle basin affected by different drains entering to the lake.

The relative abundance of investigated heavy metals in the sediments of different regions of Lake Burrullus was the same as that found for its particulate matter (ppm). This notice was in agreement with that found by Faragallah (2004) in the sediments of Abu- Qir Bay. In our study, the metal variations may be due to the water of the continuous discharge of drainage water from various industrial, agricultural and domestic activities carried out at the wide lands surrounding the lake. Such drainage water lands are surrounding the lake. Such drainage water transports different trace elements from different sources to the elements which are Zn, Cu, Fe, Mn, and Pb and Cd compounds.

It is obvious also that the organic matter content of sediments was higher at the eastern and western parts where the lake connects with the drains. In this concern Darag (1984) found that in contradiction to the overlying water, the sediment in the western basin was relatively richer with organic matter if compared with other areas.

It has been proved for a long time that, the northern delta can receive any discharged pollutants without any burden on their environment.

It is attempted in the present study to study the effect of drainage water discharged to Lake Burullus, the second largest one among the north delta lakes, on the level of pollution of its water and bottom sediments with six trace elements namely Zn, Cu, Fe, Ni, Pb and Cd during the period 2004 to 2005.

Comparing heavy metals data with the previously studied metals in lake waters, copper showed lower values, this may be due to its precipitation or lowering in its source. Other metals increased due to its increase in drainage water or its dissolution from sediments affected by environmental conditions (Table 6). Comparing the data of heavy metals with those previously studied, we can conclude that, Iron and lead in sediments decreased than those previously studied. While other metal were higher in the present study (Table 7).

ASSESSMENT OF SEDIMENT CONTAMINATION

Sediment quality index (SQI)

From the previous discussion, it is clear that maximum (first) eigenvalue represents the largest information content of standardized pollution matrices. It represents 29.03% of each heavy metal. The second Eigenvalue (14.455%), the third (12.536%), the fourth (11.12%), the fifth (9.057%) and the sixth represent (7.493%) of each heavy metal. A Sediment Quality index (SQI) is proposed as given by the following formula (El-Iskandarani et al., 2004).

$$SQI = \sum_{n=1}^{n} (\lambda_n / \sum \lambda) \times PC_n$$

where n: is the number of effective components.

For PC assessment model where λ_n are the Eigen values of the effective components and PC_n are the n critical principal component scores. Table (8) displays the principal component scores and sediment quality index for sediment parameters at each station. It displays the sediment quality index at the hot spots and cleanest area of the lake. It showed that the highest sediment quality index was 0.83, 0.71, 0.46 and 0.41 for Stations XIX, XVII, XV and VI, respectively.

The highest SQI showed the highest (0.83) at Station XIX of Fe (10100 µg/g), Mn (2030), Cu (50.35 µg/g), Zn (194.73 µg), Cd (9.26 µg/g) and Pb (3.09 µg/g).The lowest sediment quality index -0.67, -0.61 and -0.48 were observed at Stations VII, XVIII and I, respectively. The Station VII which indicate the least polluted station for all heavy metals showed the lowest SQI with metal concentrations of Fe (5568 µg/g), Mn (1135), Cu (64.47 µg/g), Zn (458.56 µg), Cd (15.21 µg/g) and Pb (9.33 µg/g).

It is difficult to make an overall assessment of the

Table 6. Comparison between some metals concentrations obtained in the present study and some previous studies of Lake Burullus.

Time of study	Eastern Basin	Middle Basin	Western Basin	Lake average	Reference
		Average Zinc concentration (µg/l)			
March 1997-March 1998	12.00	4.94	3.33	6.76	Radwan 2000
Year 2000	8.81	4.77	3.57	6.42	Radwan and Shakweer (2002)
Year 2001	15.22	8.28	6.82	11.23	Radwan and Shakweer (2003)
Year 2002	19.58	12.78	11.26	15.65	Radwan and Shakweer (2004)
Winter 2004	24.52	29.34	34.48	29.45	Present study
Year 2005	31.69	30.27	30.29	30.75	
		Average Copper concentration (µg/l)			
March 1997-March 1998	5.84	3.10	1.63	3.52	Radwan (2000)
Year 2000	5.40	2.69	5.14	4.45	Radwan and Shakweer (2002)
Year 2001	9.75	5.82	8.15	8.12	Radwan and Shakweer (2003)
Year 2002	14.44	8.61	15.36	12.68	Radwan and Shakweer (2004)
Winter 2004	1.85	2.55	2.41	2.27	Present study
Year 2005	2.54	3.90	3.46	3.30	
		Average Iron concentration (µg/l)			
March 1997-March 1998	5.44	1.16	0.79	2.46	Radwan (2000)
Year 2000	3.66	1.45	2.72	2.73	Radwan and Shakweer (2002)
Year 2001	12.67	6.42	9.98	10.05	Radwan and Shakweer, 2003
Year 2002	21.71	12.94	23.46	19.14	Radwan and Shakweer, 2004
Winter 2004	18.60	8.51	14.91	14.01	Present study
Year 2005	18.60	18.65	14.86	17.37	
		Average Lead concentration (µg/l)			
March 1997-March 1998	2.94	2.59	2.74	2.76	Radwan 2000
Year 2000	2.34	1.26	3.60	2.23	Radwan and Shakweer, 2002
Year 2001	6.51	3.99	5.64	5.50	Radwan and Shakweer, 2003
Year 2002	8.05	5.96	7.65	7.27	Radwan and Shakweer, 2004
Winter 2004	0.73	13.26	1.70	5.23	Present study
Year 2005	5.52	3.41	3.46	4.13	
		Average cadmium concentration (µg/l)			
March 1997-March 1998	3.63	1.21	0.94	1.93	Radwan 2000
Year 2000	3.54	1.54	2.03	2.57	Radwan and Shakweer, 2002
Year 2001	7.32	3.28	3.66	5.24	Radwan and Shakweer, 2003
Year 2002	9.00	4.36	7.06	7.06	Radwan and Shakweer, 2004
Winter 2004	4.58	3.56	1.83	3.32	Present study
Year 2005	3.25	2.74	1.11	2.37	
		Average Manganese concentration (µg/l)			
Winter 2004	6.44	11.82	7.80	8.69	Present study
Year 2005	5.62	7.75	5.81	6.39	

Table 7. Comparison between some metals concentrations obtained in the present study and some previous studies of Lake Burullus.

	Metals sediments (µg/g)				References
		East	Middle	West	
Year 1995	Fe	52950	50425	50125	El-Deek, et al, 1995
	Cu	54.5	73.7	67.85	
	Zn	86.25	61	82.25	
	Mn	755.75	661.75	644.75	
Year 2000	Fe	12114	13352	33033	Radwan et al, 2002
	Cu	21.87	21.32	35.47	
	Zn	52.33	51.78	94.40	
	Pb	23.96	13.60	19.80	
	Cd	1.94	1.74	2.60	
Year 2001	Fe	24148	12835	40827	Shakweer et al, 2004
	Cu	23.78	21.10	30.42	
	Zn	53.94	55.09	94.53	
	Pb	22.98	14.17	20.88	
	Cd	2.70	2.60	3.36	
Winter 2004- winter 2005	Fe	8387.50	7902.13	7156.67	Present study
	Mn	1245.30	1392.20	961.90	
	Cu	82.58	82.76	85.23	
	Zn	292.41	254.89	237.37	
	Cd	9.26	11.64	10.14	
	Pb	4.26	4.45	2.99	

Table 8. Principal component scores and sediment quality index of Lake Burullus sediments at each station.

Stations	PC1	PC2	PC3	PC4	PC5	PC6	SQI
I	-0.705	0.327	0.021	-2.096	-0.837	-0.236	-0.48
II	0.024	0.684	0.033	-0.847	-1.122	1.989	0.06
III	-0.020	1.592	-3.525	1.226	-0.104	-0.634	-0.14
IV	-0.149	0.218	-0.458	-0.328	1.243	1.385	0.11
V	-1.269	-0.165	0.452	0.936	1.675	1.026	0.00
VI	0.032	2.106	1.706	-0.354	-0.333	-0.582	0.41
VII	-1.419	-0.457	-0.298	-1.407	0.937	-1.042	-0.67
VIII	-0.780	0.633	0.533	0.410	0.716	0.010	0.04
IX	-1.399	0.840	0.681	0.363	-0.531	-0.527	-0.25
X	0.294	-0.777	-0.054	0.359	-1.845	-0.424	-0.19
XI	0.604	-1.242	0.091	0.005	-0.816	0.417	-0.03
XII	-0.288	-0.687	0.811	1.714	-1.349	0.132	0.00
XIII	0.755	-1.354	-0.340	0.501	-0.685	0.272	-0.01
XIV	-0.083	-1.827	-0.224	-0.078	1.475	0.817	-0.13
XV	0.823	-0.051	1.001	1.452	1.033	-1.993	0.46
XVI	-0.735	0.092	-0.080	0.751	-0.537	0.658	-0.13
XVII	2.291	0.232	0.263	-0.431	0.899	-0.693	0.71
XVIII	-0.141	-1.132	-0.699	-1.564	-0.212	-1.657	-0.61
XIX	2.166	0.965	0.085	-0.612	0.393	1.082	0.83

Table 9. The background levels of heavy metals (µg/g) in the many international reference areas, and pollution classificat

Stations	Fe	Mn	Cu	Zn	Cd	Pb
Back ground value	46912.4	597	14	67	0.38	8
Non polluted		<300	<25	<90		<40
moderately polluted		300-500	25-50	90-200		40-60
Heavily polluted		>500	>50	>200		>60

Background level: Zn and Cu (UNEP, 1993; Bryan and Langeton, 1992); Pb (USPHS, 1997); Mn (Goldschmidt, 1954).

Table 10. Geoaccumalation index (Igeo) according to Müller (1969)

Igeo	class	Pollution Intensity
>5	6	Very strong polluted
4-5	5	Strong to very strong polluted
3-4	4	Strongly polluted
2-3	3	Moderately to strongly polluted
1-2	2	Moderately polluted
0-1	1	Un polluted to moderately polluted
0	0	unpolluted

degree of metal contamination in estuarine and marine sediments (Rubio et al., 2000). This is a consequence of variations in analytical procedures between studies and the presence of¨ an unknown natural background in the sediment. In the present study, many approaches were employed to evaluate sediment pollution, comparison with the background value and sediment quality guidelines, calculation of contamination factors (Cf), degree of contamination (Dc), enrichment factor (EF) and toxicity guidelines of heavy metals.

Comparison with the background value

The levels of heavy metals (µg/g) in the sediments of Lake Burullus basins and drains compared to the background values are shown in Table (9).The background value of` the different elements were defined, depending on the international standards: Zn and Cu (UNEP, 1993; Pazos-Capeáns et al., 2004). Other back ground values from measured concentrations in sediments of the lake on the less than 65 µm fraction of the size. An index of metal pollution in the region has been attempted to evaluate the extent of pollution.

The concentrations of Mn, Cu, Zn and Cd higher than the background level concentrations for all stations. The concentrations of iron and lead were lower than the background values.

Geo accumulation index (I_{geo})

An index of geoaccumulation (I_{geo}) was originally defined by Müller (1969), in order to determine and define metal contamination in sediments by comparing current concentrations with back ground levels. It was also to clarify the extent of heavy metals contamination associated with the sediments and can be calculated by the following equation:

$$I_{geo} = \log_2 (C_n / 1.5 \times B_n)$$

where C_n is the measured concentration of the element n in sediment sample and B_n is the background concentration of the element n. The factor 1.5 is used because of possible variations of the background data for a given metal in the environment as well as anthropogenic influences.

The index of geochemical consists of seven grades or classes as in Table 10. The calculated geoaccumulation (I_{geo}) (Table 11) indicates that this has to be considered as moderately polluted with respect to Cd and unpolluted to moderately polluted with respect to Zn, Cu and Mn for the lake waters and drains. Lake was unpolluted with respect to Fe and Pb. This agreed with the comparison with the background values.

Load pollution index (LPI)

In order to estimate the overall pollution level of the

Table 11. Calculated Geoaccumulation index for sediment samples of Lake and drains.

Stations	Geoaccumulation index					
	Cd	Pb	Fe	Zn	Cu	Mn
I	1.01	-0.49	-0.94	0.68	0.64	0.00
II	1.20	-1.31	-0.92	0.68	0.66	0.13
III	1.29	-1.06	-1.01	0.32	0.78	0.04
IV	1.26	-0.52	-0.87	0.25	0.73	0.06
V	1.42	-0.53	-1.01	0.34	0.96	0.14
VI	1.15	-0.78	-1.06	0.42	0.79	0.02
VII	1.43	-0.35	-1.10	0.66	0.73	0.10
VIII	1.31	-0.76	-0.96	0.33	0.85	-0.04
IX	1.22	-0.90	-1.12	0.40	0.93	0.01
X	1.22	-0.90	-0.93	0.39	0.76	0.10
XI	1.02	-0.65	-0.92	0.43	0.92	0.26
XII	1.22	-0.78	-0.98	0.21	0.88	0.10
XIII	1.23	-1.12	-0.86	0.41	0.92	0.22
XIV	1.35	-0.40	-0.90	0.47	1.03	0.25
XV	1.46	-1.20	-0.84	0.26	1.01	0.17
XVI	1.10	-0.65	-1.01	0.37	1.01	-0.01
XVII	1.32	-0.69	-0.86	0.32	0.73	0.30
XVIII	1.24	-0.82	-0.94	0.44	0.66	0.30
XIX	1.21	-0.83	-0.84	0.29	0.62	0.36

samples, the load pollution index (LPI) (Arias et al., 2008) was determined:

$$\text{LPI}=\prod_{n=1}^{n=x}(\text{EF}_n)^{1/x}$$

where EF is the enrichment factor defined as EF $=C_n/B_n$; C_n represents the measured concentration of the metal n and B_n is the background concentration of the metal n; x is the number of metals considered.

The LPI was calculated for all stations (Table 12), the load pollution index showed lower values of 1.78, 1.72 and 1.85 at Stations II, III and IX, respectively. The higher values observed of 2.49, 2.63 and 2.99 at Stations V, VII and XIV, respectively. The middle and the western part of the lake were higher polluted than the eastern part of the lake. This may be attributed to the effect of drains in the middle and western part of the lake.

Contamination factors (CF)

The level of contamination can be expressed by the contamination factor (CF); (Hökanson, 1980). It was calculated as follows:

Cf = (Metal content in the sediment) / (Metal content in natural reference sediment)

According to Hökanson (1980) the contamination factor was classified into four groups: Cf < 1 refers to the low contamination factor; 1≤ Cf < 3 refers to the moderate contamination factor; 3≤ Cf < 6 refers to the considerable contamination factors; 6≤ Cf refers to the very high contamination factor.

Copper, Cadmium and lead background values obtained by Bervoets and Blust (2003). The other background values obtained by Sheriadah, and Okbah (2002).

The values of contamination factor (Cf) are shown in Table 12. Very high contamination was recorded at all stations for copper and cadmium. Manganese showed moderate contamination factor in lake at whole. Iron and lead showed low contamination factor in lake at whole. Very high contamination was recorded at Stations I, II and VII for zinc while Station XII, XV and XIX showed moderate contaminations. Low contamination factor was recorded at all stations of the lake and drains for iron and lead.

Degree of contamination (Dc)

Degree of contamination (Dc) defined as the sum of all contamination factors for a given basin (Hökanson, 1980):

$$\text{Dc} = \sum_{i=1}^{6} C_f^i$$

Table 12. Calculated contamination factor, degree of contamination and load pollution index for sediment samples of Lake and drains.

Stations	Contamination factor						DCf	LPI
	Fe	Mn	Cu	Zn	Cd	Pb		
I	0.17	1.52	6.58	7.19	15.37	0.49	31.30	2.12
II	0.18	2.04	6.78	7.21	23.66	0.07	39.94	1.78
III	0.15	1.64	8.94	3.12	29.53	0.13	43.51	1.72
IV	0.20	1.71	7.97	2.68	27.50	0.45	40.52	2.12
V	0.14	2.08	13.69	3.26	39.37	0.45	58.98	2.49
VI	0.13	1.59	9.23	3.96	21.39	0.25	36.56	1.85
VII	0.12	1.90	8.09	6.84	40.03	0.67	57.65	2.63
VIII	0.17	1.38	10.50	3.21	30.42	0.26	45.94	1.99
IX	0.11	1.54	12.76	3.77	24.79	0.19	43.17	1.85
X	0.18	1.91	8.70	3.65	24.82	0.19	39.44	1.92
XI	0.18	2.73	12.39	4.00	15.55	0.34	35.18	2.24
XII	0.16	1.88	11.36	2.43	24.82	0.25	40.88	1.92
XIII	0.21	2.51	12.40	3.81	25.32	0.11	44.36	2.03
XIV	0.19	2.66	16.18	4.47	33.24	0.59	57.33	2.99
XV	0.22	2.23	15.22	2.75	43.21	0.09	63.71	2.08
XVI	0.15	1.48	15.24	3.50	18.92	0.33	39.62	2.04
XVII	0.21	2.99	8.09	3.13	31.45	0.30	46.17	2.30
XVIII	0.17	3.00	6.91	4.08	26.34	0.23	40.74	2.11
XIX	0.22	3.40	6.29	2.91	24.37	0.22	37.40	2.04
Back ground value	46912.4	597	8	67	0.38	14		

For the description of the degree of contamination the following terminologies have been used: Dc < 7 low degree of contamination; 7<Dc<14 moderate degree of contamination; 14≤Dc<28 considerable degree of contamination; Dc > 28 very high degree of contamination.

All stations of the lake and drains are considered as of very high degree of contamination.

Enrichment factors (EF)

The enrichment factor (EF) was evaluated by computing the ratios of metal concentrations to Fe concentration (Zabetoglou et al., 2002). The enrichment factor for each metal was calculated from the formula stated (Rule, 1986; Rubio et al., 2000):

$$Ef = \frac{(Metal/Fe)_{Sample}}{(Metal/Fe)_{Crust}}$$

The enrichment factors (Ef) of trace metals in the lake sediments were shown in Table 13.

The values of enrichment factors, For Mn, revealed a maximum value (12.81) at Station XVIII in the western drain part of the lake and a minimum value (6.15) at Station IV in eastern lake area.

For Cu, it revealed a maximum value (17.62) at Station IX in the western lake area while the minimum value (4.62) was observed in Station XIX in the western drain part of the lake. For Zn, it revealed a maximum value (65.67) at Station VII in the middle lake area while the minimum value (15.10) was observed in Station IV in the eastern lake area. Table 13 revealed the maximum value (1147.25) for Cd at Station VII in the middle lake area while the minimum value (295.50) was observed at Station XI in the eastern drain part.

It revealed the maximum value (10.56) for Pb at Station VII in the middle lake area while the minimum value (0.77) was observed at Station II in the eastern lake area.

We can summarize that, the lake waters were more polluted in middle part of the lake and the eastern part revealed least pollution.

Sediment quality guidelines (SQG)

To evaluate the level of contamination, sediments were classified as: non-polluted, moderately polluted and heavily polluted, based on the SQG of US-EPA (Perin et al., 1997). Table 9 shows that Pb is considered as unpolluted comparing with the data reported by SQG. The contamination levels (Zn, Cu and Mn) were heavily polluted in all stations. The only exception was Station IV and XIX which revealed moderately pollution with Zn.

Table 13. Calculated enrichment factor for sediment samples of Lake and drains.

Stations	Ef					
	Cd	Pb	Fe	Zn	Cu	Mn
I	306.60	5.35	1.00	48.01	6.09	6.48
II	444.21	0.77	1.00	45.29	5.91	8.22
III	682.96	1.66	1.00	24.15	9.60	8.15
IV	462.00	4.18	1.00	15.10	6.22	6.15
V	924.00	5.80	1.00	25.58	14.92	10.44
VI	553.20	3.55	1.00	34.31	11.09	8.79
VII	1147.25	10.56	1.00	65.67	10.77	11.67
VIII	622.46	2.96	1.00	21.98	9.98	6.05
IX	736.76	3.10	1.00	37.53	17.62	9.82
X	477.18	2.02	1.00	23.48	7.77	7.87
XI	295.50	3.56	1.00	25.42	10.93	11.11
XII	542.55	2.99	1.00	17.80	11.53	8.79
XIII	416.54	1.03	1.00	21.01	9.47	8.83
XIV	602.80	5.96	1.00	27.16	13.62	10.35
XV	682.81	0.82	1.00	14.52	11.17	7.54
XVI	442.88	4.31	1.00	27.43	16.57	7.41
XVII	519.74	2.78	1.00	17.34	6.21	10.57
XVIII	525.53	2.53	1.00	27.28	6.40	12.81
XIX	385.07	1.93	1.00	15.38	4.62	11.51

Assessment of toxicity of heavy metals in sediments

To protect aquatic life, the Cadian Ministry of Environment (CCME) has derived two reference values for some 30 substances in freshwater and marine sediments: a threshold effect level (TEL) and a probable effect level (PEL). These two values have been adopted for the assessment of sediment quality in Quebec, and three other levels were derived to define all of the intervention levels needed for sediment management in Quebec under a diversity of contexts. The three new sediment quality criteria were defined using the CCME database and a calculation method similar to the one used to determine the TEL and the PEL. They are (1) the rare effect level (REL), (2) the occasional effect level (OEL) and (3) the frequent effect level (FEL) (Criteria for the Assessment of Sediment Quality, 2008). This set of criteria constitutes a screening tool for assessing the degree of contamination of sediment (Table 14). Employed in conjunction with natural background levels, these quality criteria can prevent the contamination of sites that are sensitive to inputs of anthropogenic contaminants. The criteria can also be combined with other assessment tools, such as toxicity tests and biological field studies, to determine the most appropriate management method for dredged material based on its degree of contamination. The sediment quality criteria can also serve as indicators of the remedial measures required at contaminated sites and help to define restoration objectives. Another quality guideline is interim freshwater sediment quality guidelines (ISQGs; dry weight) (Canadian Sediment Quality Guidelines, 2002).

Cd values increased than the five quality guide values but, it showed lower than EFL values in most stations but exceeded at Stations V, VII, VIII, XIV and XV.

Pb values for all station were below all limits of sediment guidelines. Cu values are higher than four but less than PEL and FEL sediment gridline values for most stations

Zn values exceeded the REL, TEL OEL and ISQG values in all stations. It exceeded the PEL values at Stations I, II and VII. All Zn values were located below the FEL guide line values.

Risk assessment

The model of risk assessment was developed by national institute of public health and environmental protection. Exposure assumption model is to asses the risk of heavy metals on humans in relation to the recreational activities. Sediment and suspended matter used as input parameters. During recreational activities, human exposure may occur via three different pathways ingestion, inhalation and dermal contact of human exposure through dermal contact of skin with contaminated sediments, with river bank soil or with water. Exposure through ingestion occurs through contaminated sediments. Suspended matter, surface water during swimming and via consumption of fish (Tuner, 1989).

According to this model, human risk assessment was

Table 13. Calculated Enrichment factor for sediment samples of Lake and drains.

Stations	Ef					
	Cd	Pb	Fe	Zn	Cu	Mn
I	306.60	5.35	1.00	48.01	6.09	6.48
II	444.21	0.77	1.00	45.29	5.91	8.22
III	682.96	1.66	1.00	24.15	9.60	8.15
IV	462.00	4.18	1.00	15.10	6.22	6.15
V	924.00	5.80	1.00	25.58	14.92	10.44
VI	553.20	3.55	1.00	34.31	11.09	8.79
VII	1147.25	10.56	1.00	65.67	10.77	11.67
VIII	622.46	2.96	1.00	21.98	9.98	6.05
IX	736.76	3.10	1.00	37.53	17.62	9.82
X	477.18	2.02	1.00	23.48	7.77	7.87
XI	295.50	3.56	1.00	25.42	10.93	11.11
XII	542.55	2.99	1.00	17.80	11.53	8.79
XIII	416.54	1.03	1.00	21.01	9.47	8.83
XIV	602.80	5.96	1.00	27.16	13.62	10.35
XV	682.81	0.82	1.00	14.52	11.17	7.54
XVI	442.88	4.31	1.00	27.43	16.57	7.41
XVII	519.74	2.78	1.00	17.34	6.21	10.57
XVIII	525.53	2.53	1.00	27.28	6.40	12.81
XIX	385.07	1.93	1.00	15.38	4.62	11.51

Table 14. Criteria (µg/l) for the assessment of freshwater sediment quality.

Metals	REL[a]	TEL[a]	OEL[a]	PEL[a]	FEL[a]	ISQG[b]
Zn	80	120	170	310	770	123
Cu	22	36	63	200	700	35.7
Cd	0.33	0.6	1.7	3.5	12	0.6
Pb	25	23	52	91	150	35
Fe				43766		21200
Mn				1100		460

calculated as a function of recreational activities in relation to environmental pollution (example, by heavy metals). An existing exposure assessment model was applied to estimate human health risk.

Risk assessments for water, suspended matter and sediments of Lake Burullus

The results of the health risk assessment indicate that sediments contamination by various heavy metals (Fe, Mn, Cu, Zn, Pb and Cd) in Lake Burullus may present a health Hazard. The following equations were used for calculate the assessment of the human risk (Albering et al., 1999).

Ingestion of contaminated sediments (ICS) (mg / kg /day') =(Cs × IRs × EF × AF)/ BW

where Cs = concentration of the contaminant in sediment (mg/kg dw), IRs = ingestion rate of sediment (kg dw/exposure day), EF = exposure frequency (days/365 days), AF = Absorption factor (unitless) and BW = body weight (kg).

Dermal contact with contaminated sediments (DCCS) (mg/ kg/day') = (Cs × SAs × ADs × ASs × Mf × EDs × EF)/BW

where SAs = dermal surface area for sediment exposure (m^2), AD = dermal adherent rate for sediment (mg/cm^2), Ass = dermal absorption rate for sediment (liter/h), Mf = matrix factor (unitless), and EDs = exposure duration from dermal exposure to sediment (h/day).

Daily exposure (mg kg^{-1} day^{-1}) = [(6 × daily exposure child) ÷70] + [(64 × daily exposure adult) ÷ 7]

Table 15. Risk Assessments for water, suspended matter and Sediments of Lake Burullus on human beings

Region		Lake		Drains	
Metal	**Fraction**	**Child**	**Adult**	**Child**	**Adult**
Fe	Ingestion of sediments	14.3580	10.7685	17.4351	13.0763
	Dermal contact with sediments	14.9380	19.3832	18.1394	23.5373
	Ingestion of surface water	1.6890	0.1689	1.9360	0.4149
	Ingestion of suspended matter	0.7837	0.1679	1.0605	0.2273
	Total	31.7687	30.4886	38.5710	37.2557
	Daily exposure	281.4756		343.9300	
Mn	Ingestion of sediments	2.0431	1.5323	2.9584	2.2188
	Dermal contact with sediments	2.1256	2.7581	3.0779	3.9938
	Ingestion of surface water	0.6800	0.0680	0.7470	0.1601
	Ingestion of suspended matter	0.1163	0.0249	0.1249	0.0268
	Total	4.9650	4.3834	6.9081	6.3994
	Daily exposure	40.5019		59.1008	
Cu	Ingestion of sediments	0.1503	0.1127	0.1804	0.1353
	Dermal contact with sediments	0.1564	0.2029	0.1877	0.2436
	Ingestion of surface water	0.3210	0.0321	0.3360	0.0720
	Ingestion of suspended matter	0.0158	0.0034	0.0117	0.0025
	Total	0.6435	0.3511	0.7159	0.4534
	Daily exposure	3.2654		4.2071	
	Hazard index	0.02 - 0.05			
Zn	Ingestion of sediments	0.6140	0.4605	0.4654	0.3491
	Dermal contact with sediments	0.6388	0.8289	0.4843	0.6284
	Ingestion of surface water	3.0470	0.3047	2.4840	0.5323
	Ingestion of suspended matter	0.0348	0.0075	0.0381	0.0082
	Total	4.3347	1.6016	3.4718	1.5179
	Daily exposure	15.0148		14.1754	
	Hazard index	1.08 - 1.2			
Cd	Ingestion of sediments	0.0213	0.0160	0.0204	0.0153
	Dermal contact with sediments	0.0221	0.0287	0.0212	0.0275
	Ingestion of surface water	0.2900	0.0290	0.2920	0.0626
	Ingestion of suspended matter	0.0043	0.0009	0.0029	0.0006
	Total	0.3377	0.0746	0.3365	0.1060
	Daily exposure	0.7111		0.9978	
	Hazard index	0.11 - 0.16			
Pb	Ingestion of sediments	0.0092	0.0069	0.0075	0.0056
	Dermal contact with sediments	0.0096	0.0124	0.0078	0.0101
	Ingestion of surface water	0.3750	0.0375	0.2490	0.0534
	Ingestion of suspended matter	0.0009	0.0002	0.0007	0.0001
	Total	0.3947	0.0570	0.2649	0.0692
	Daily exposure	0.5547		0.6552	
	Hazard index	1.7 - 4.4			

The results were expressed in Table 15. This health risk assessment indicate that sediment contamination by Cu and Zn in lake Burullus present a health hazard, if the risks are calculated on the basis of the standard exposure model including data of actually measured contaminant concentrations in surface water and suspended matter.

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