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Ecological implications of heavy metal concentrations in the sediments of Burullus Lagoon of Nile Delta, Egypt

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ABSTRACT

This paper examines the spatial and temporal distribution of heavy metals (Fe, Al, Cu, Zn, Mn, Cd, Pb and Ni) from three short sediment cores collected from Burullus lagoon of the Nile delta, Egypt. ^{210}Pb and ^{137}Cs measurement is applied to understand sedimentation rate and related chronology. Remarkably low isotopic activities and intensive bioturbation in the lagoonal sediments rendered age determination difficult. Samples with detectable ^{137}Cs in the upper core sediments together with sediment lithology could help infer a sedimentation rate of about 2.0 mm yr^{-1}, thereby indicating post-dam (after 1964) sedimentation of the upper 10-cm core sediments. Our results demonstrate that most heavy metals in the surficial sediments after normalization to Al decrease seaward, showing a function of distance to the sewerage outlet on the inland lake coast. Also, there is an upwardly increasing trend of normalized heavy metals, especially in the upper 10-cm core sediments. Relevancy analysis has identified Mn, Pb and Cd as the diagnostic heavy metals in Burullus lagoon, most likely derived from Tanta and Kafrelsheihk, the major downtowns in the central Nile delta plain, from where wastewaters are directly discharging into the lake via canal networks. Although Burullus lagoon is presently least affected by pollution as compared to other major lagoons of the Nile delta, the increasing quantities of diagnostic metals, especially Mn, are extremely toxic, as they are potentially linked to the risks of digestive issues and pancreatic cancer reportedly. The situation calls for a rational planning for sewerage treatment in the protected Burullus coast.

1. Introduction

The delta coasts of the world are densely populated and highly industrialized during the past century. This has discharged a large quantity of wastewaters into the estuaries, leading to severe pollution of the wetlands and the associated social issues in relation to degraded environment (Abdel-Moati and El-Sammak, 1997; Soliman et al., 2006). Heavy metals of anthropogenic origin are toxic pollutants, which are able to transfer hierarchically into human society through the food chain (Farmer, 1991), and some of which, under certain circumstances, can be further transformed into more toxic compounds (Chen et al., 2000). Analyses of spatial and temporal distribution of heavy metals in the delta coasts are useful to recognize the degradation processes of wetlands and trace sources of pollutants for better environmental assessment and management.

Environmental issues of the Nile delta coast have become more prominent recently due to increasing population and intensifying industry (Abdel-Moati, 1998; El-Rayis, 2005). Four large coastal lagoons are being ecologically degraded owing to the discharge of untreated wastewaters into the lakes. For example, sewerage output has extended to Mariut lagoon from Alexandria on the northwestern Nile coast and that from Port Said, Damietta and Matariya to Manzala lagoon on the northeastern coast, where heavy metals are significantly enriched in the water and sediments. Cu and Cd in Manzala lake have gone up almost 60% and Zn has increased almost twofold since last decades (Abdel-Moati, 1998). Nowadays, Mariut and Manzala lagoons are the most polluted and Idku and Burullus follow behind. Presently these two lakes are facing critical environmental pressures from local industries and urbanization with the increasing pollutants being expelled towards the lake coast (Kamal and Magdy, 2005).

Heavy metals and related environmental conservation of the Nile coast calls for more attention. Many projects implemented have targeted heavy metal distribution and transportation in relation to aquacultural health and societal response. Abdel-Moati

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and El-Sammak (1997) found that Cd and Pb expelling into the lagoons has increased by 8–70 times during the past 25 years. Pancreatic cancer risk in the Manzala region seems to be closely associated with cadmium concentration (Soliman et al., 2006). Siegel et al. (1994) stated that Pb, Zn Hg and Cu enriched in Manzala lagoon were primarily due to cheaper power generators after High Aswan dam emplacement in 1964. This has considerably degraded aquacultural products both in quantity and quality in the Manzala region, where it has long been the most important aquacultural base, by providing more than 50% of aquaculture products for Egyptian.

Burullus lagoon of the central Nile delta is a UNESCO-protected area (Fig. 1). Burullus is chosen as the study area with an aim of establishing a useful heavy metal database for this relatively less polluted lake, where the existing ecological information is very limited when compared to that of other lagoons in the region. This paper examines the spatial and temporal variations in distribution of heavy metals in the lake sediments, assisted by ^{210}Pb and ^{137}Cs measurements, which has not been substantially attempted in the previous studies. Through this analysis, we defined the diagnostic heavy metals and discussed the potential sources of pollution, calling for an urgent attention on ecological safety.

2. Regional setting

The Nile delta lies at the southern coast of the Mediterranean Sea (30°00′–31°40′ N and 30°00′–32°30′E; Fig. 1A), which is under an arid climate with annual precipitation of <100 mm (Appleby et al., 2001). After the construction of the Aswan High dam in 1964, the annual runoff entering the sea has been dramatically reduced from 85×10^9 m^3 to $<60 \times 10^9$ m^3 (Frihy and Lawrence, 2004). Accordingly, sediment load has decreased from 178×10^6 t yr^{-1} to $50–60 \times 10^6$ t yr^{-1} (Inman and Scott, 1984), which affected sedimentation rates on the delta coast from the previous >1.0 cm/yr to the recent <0.20 cm yr^{-1} (Siegel et al., 1994; Appleby, et al., 2001), triggering wide-spread erosion along the delta coast.

Although the coast is a microtidal environment (<1.0 m), the strong littoral currents induced by huge winter storm surges prevail in the region and drive the sediments primarily eastward along the shoreline. This has been largely responsible for shaping the coastal topography. Strong marine invasion into inlands has substantially sustained the development of brackish lagoonal wetlands on the Nile coast (Hamza, 2006).

Four large lagoons occur on the Nile coast, i.e., Manzala, Burullus, Idku and Mariut from east to west (Fig. 1A). Burullus lagoon of the

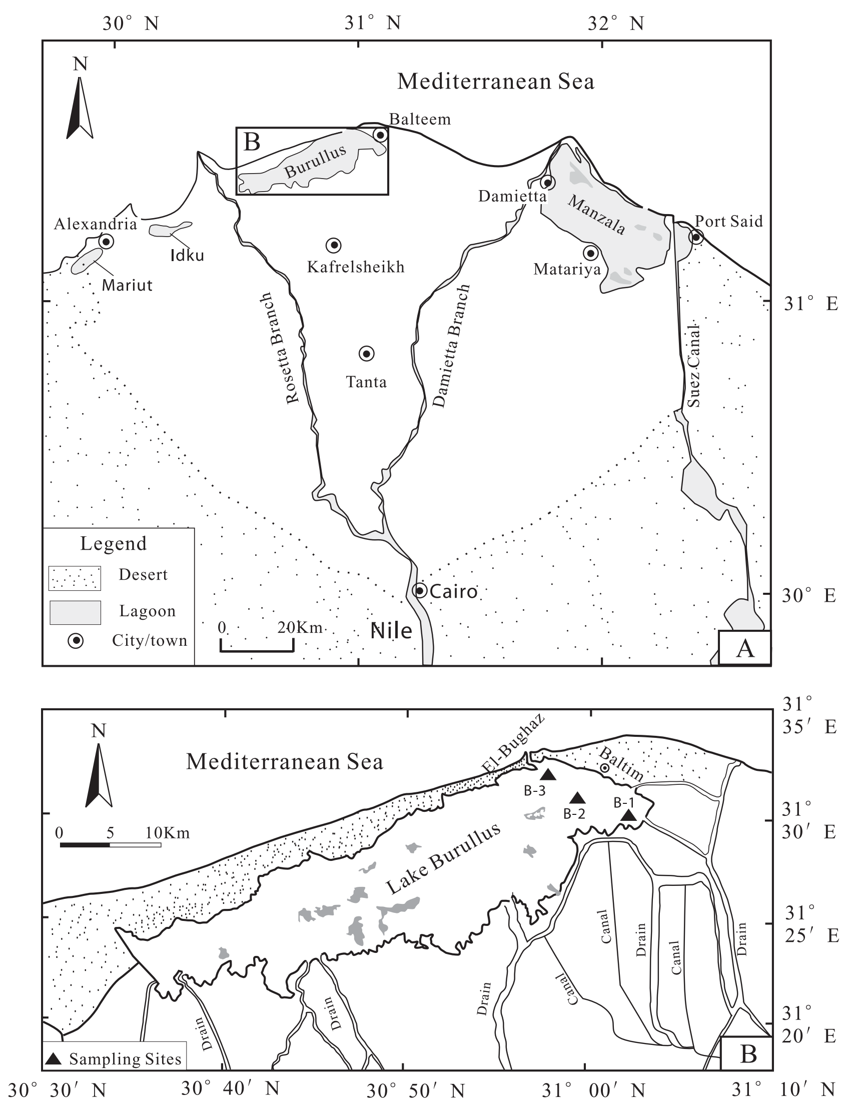

Fig. 1. A) Geographic site of the Nile delta, Egypt; B) sampling sites (B-1, B-2 and B-3) in Burullus lagoon. Note, canal networks with sewerage discharge are spread on the inland coast of the lagoon.

central Nile delta coast is 47 km long and about 5 km wide, covering a water surface area of 460 km^2. The water depth of the lagoon is less than 2 m. Al-Bughaz remains as the outlet connecting to the Mediterranean Sea (Fig. 1B), and Baltim of the eastern coast serves as the tourism center. Since 1965, pollution and eutrophication have increasingly threatened the ecosystem of the region, and Pb seems to be the toxic metal with the highest concentration in the lake (Birks et al., 2001). In the southern part of the lake coast occur the networks of the channels through which the sewerage from the local downtowns and villages directly reaches the lake (Fig. 1B).

3. Data sources and method

In 2006, three short sediment cores were recovered manually in the eastern Burullus lagoon, i.e. B1, B2, and B3, positioned in a seaward direction (Fig. 1B). B-1, closer to a sewerage outlet, is 55 cm long, B-2 is 75 cm long and B-3, nearer to the sea coast is 80 cm long. The core is 7 cm in diameter. While splitting, the core samples were collected at 3–5 cm interval, totaling 50, and placed into well-numbered plastic bags. Sediment description was also made while sampling.

In the laboratory, about 10-g wet sample was taken and dried in an oven at temperature of 105 °C. Dried samples were weighed and the water content thus was obtained. 2–5 g dried samples were taken for grinding in mortar and sieving through 100 μm mesh to remove rootlets. Samples were then packed into plastic tubes (1 cm diameter and 4 cm in height) and sealed for 3 weeks to establish equilibrium between ^{226}Ra and ^{222}Rn (^{214}Pb) by the way of preparing the samples for radionuclide analysis by gamma spectroscopy measurement (Appleby et al., 2001). A high purity germanium well type detector (ORTEC GWL-120210-S)was used for determination of ^{210}Pb (46·5 keV), ^{214}Pb (351·9 keV) and ^{137}Cs (661.7 keV). We use the peak at energy 46.5 keV to account for the total ^{210}Pb and the 351.9 keV (^{214}Pb) for supported ^{210}Pb. The difference between them is the excess ^{210}Pb. Each sample was normally counted for 24 hr to minimize the counting error.

About 10-g wet samples were taken for drying at temperature of <30 °C in oven. Samples were sieved with 200 μm mesh to remove rootlets and shell fragments, and then ground before testing. About 0.25-g ground sample was weighed into Teflon beakers, and a mixture of HNO_3–$HClO_4$–HF was added, which was digested on a hot plate. Atomic absorption spectrophotometer was used for analysis of elements Cu, Zn, Mg and Ni, inductively coupled plasma atomic absorption spectrophotometry (ICP-AES, Perkin Elmer Plasma 2000) was used for Al and Fe, and graphite furnace AAS (Z-2000) for Pb and Cd. The reagent blanks and China Stream Sediment Reference Material (GSD9) were analyzed along with the samples for quality assurance purposes. Replicate analysis of each batch of samples showed that the analytical precision was within 10% variability.

Granulometric analysis was done for all samples by using grain size analyzer (LS-13320). Sand (63–2000 μm), silt (4–63 μm) and clay (<4 μm) fraction were proportioned together with the mean grain size (Md) used in the present study. In addition, about 10-g wet samples were taken for measuring total organic matter (TOM). Samples were dried in the oven at <30 °C, and after grinding, a 5-g sample was placed in crucible for heating at a temperature of 410 °C in a muffle furnace.

4. Results

4.1. Core sediments

4.1.1. B-1

The upper part of sediment section (0–15 cm) consists of darkish gray silty clay rich in shells. The mean grain size is 34.57 μm, TOM is 9.20% and the water content is 46–48% (Fig. 2A). The middle part of sediment section (15–45 cm) is made up of dark clay with some shells. The mean grain size is 7.64 μm, TOM is 8.91% and the water content decreases to about 28% (Fig. 2A). The lower part of sediment section (45–55 cm) comprises dark silty clay with the mean grain size of 48.32 μm. No shells are seen in the sediments. TOM and water content decreases to 6.32%and 26%, respectively.

4.1.2. B-2

The upper part of sediment section (0–10 cm) consists of darkish gray silty clay rich in shell fragments and a few rootlets (Fig. 2B). The mean grain size is 10.21 μm, TOM is 6.68% and the water content reaches to 52–57%. The middle part of sediment section (10–40 cm) consists of dark silt with a few shell fragments and root traces. The mean grain size is 41.29 μm, TOM decreases to 5.35%, and the water content further reduces to 20%. The middle-lower part of sediment section (40–50 cm) is made up of dark clayey silt with the mean grain size of 25.32 μm. No shells occur in the sediments. TOM is 4.71% and the water content is 35%. The lower part of sediment section (50–75 cm) comprises gray silt with the mean grain size of 47.39 μm. TOM lowers to 4.42% and the water content is 25% (Fig. 2B).

4.1.3. B-3

The upper part of sediment section (0–20 cm) consists of gray clay rich in shell fragments (Fig. 2C). The mean grain size is 17.33 μm, TOM is about 8.42% and the water content is 20–42%. The middle part of sediment section (20–60 cm) is made up of gray to darkish gray silty clay with a few shell fragments and rootlets. The mean grain size is 13.70 μm, TOM is 11.13% and the water content increases to 60%. The lower part of sediment section (60–80 cm) consists of dark clay with a few rootlets. The mean grain size is 8.79 μm, TOM is about 11.68% and the water content further increases to 65% (Fig. 2C).

4.2. ^{210}Pb and ^{137}Cs

Our study has revealed the extremely low excessive ^{210}Pb and ^{137}Cs activity in the core sediments (Fig. 3A,B,C). The result shows that in the upper part of the sediment section (0–15 cm) of B-1, there are some samples whose ^{210}Pb excess values remain nearly positive (Fig. 3A). Below that horizon, with some undetectable and other detectable samples, an irregular depth profile of ^{210}Pb is formed. A similar irregular ^{210}Pb pattern with only one detectable sample occurred on the core top of B-2 and B-3 as well (Fig. 3B, C). Notably, the top 3 samples of ^{137}Cs at the core depth of <10 cm of B-1 remain detectable, while the rest are undetectable in the down core section. There are only 1 or 2 samples detectable in the upper core sediment of <5 cm of B-2 and B-3 (Fig. 3A, B, C).

5. Heavy metals

5.1. Spatial distribution

The analysis of the three core samples indicated the spatial distribution of heavy metals in the lake. The absolute content of Cu, Ni, Al, and Fe increases seaward from B-1 to B-3, while Mn, Cd and Pb showed a decreasing trend and Zn fluctuates in the seaward profile (Fig. 4A). We used Al to normalize metal concentrations to reduce the influence of particle size. After normalization, all heavy metals, except Cu, tended to decrease seaward (Fig. 4B).

5.2. Temporal distribution

5.2.1. B-1

In the sediment core section between 55 and 40 cm, absolute contents of Cu, Zn, Ni, Al and Fe increased upward and then reduced further upward. Mn and Pb stayed relatively stable in the sediment

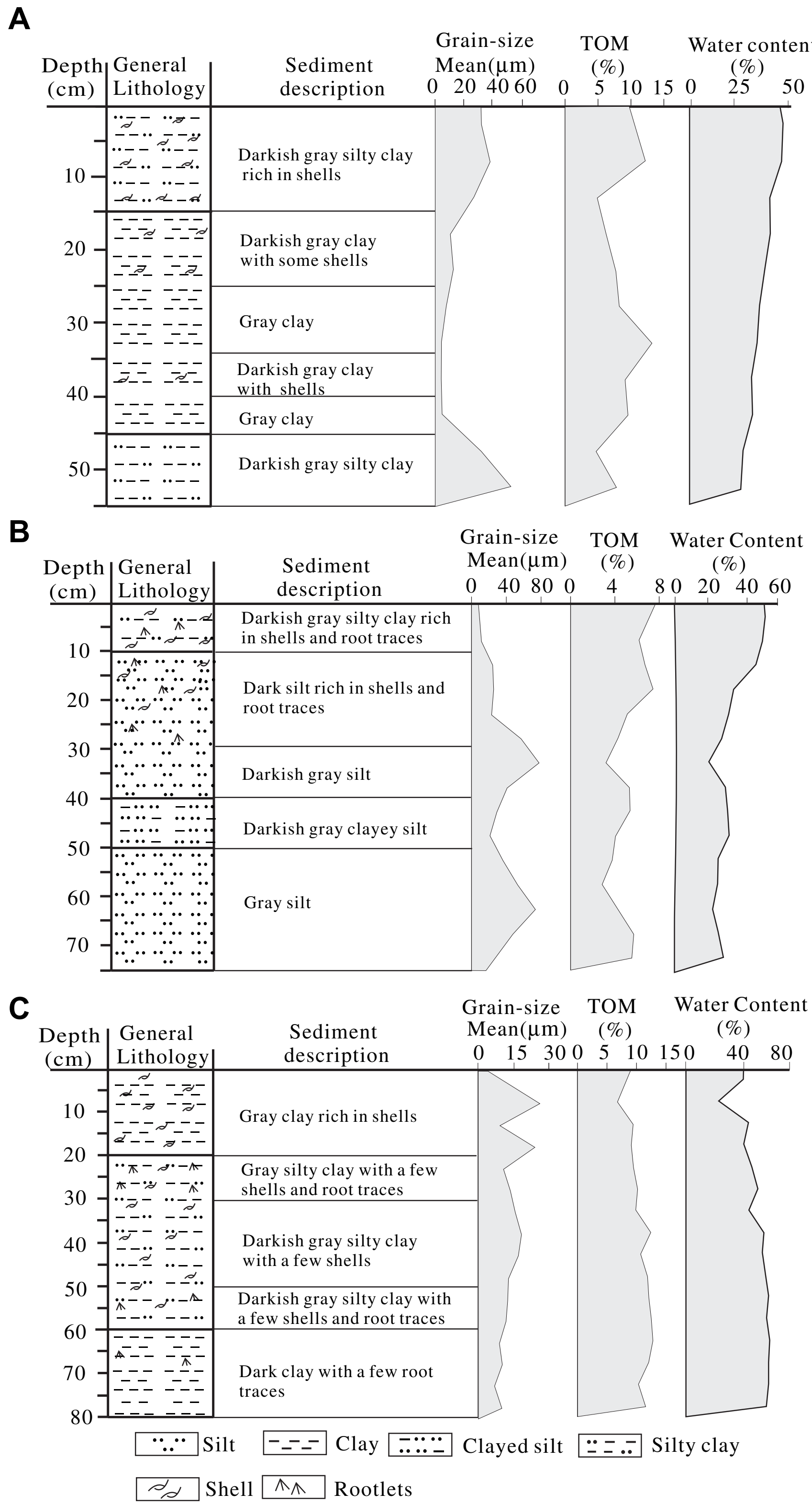

Fig. 2. Downcore distribution of sediments, mean grain size, total organic matter (TOM) and water content in B-1 (A), B-2 (B) and B-3 (C).

section of 55–25 cm from where it increased upward. Cd goes up from the core bottom (Fig. 5B-1-I). After normalization to Al, Cu appears stable through the core sediments; Zn, Ni, Mn, Fe, and Pb decreased slightly in 55–10 cm followed by an obvious increase toward the core top. Cd showed an increasing trend above the core depth of 45 cm (Fig. 5B-1-II).

5.2.2. B-2

Absolute Cu remained fairly stable throughout the core sediments, and Al increased upward apparently before declining at about 10 cm, while Zn, Ni, Fe and Cd fluctuated throughout (Fig. 5B-2-I). Pb increased from the core bottom, especially above 10 cm. Mn fluctuated, but increased obviously upward from the core depth of about

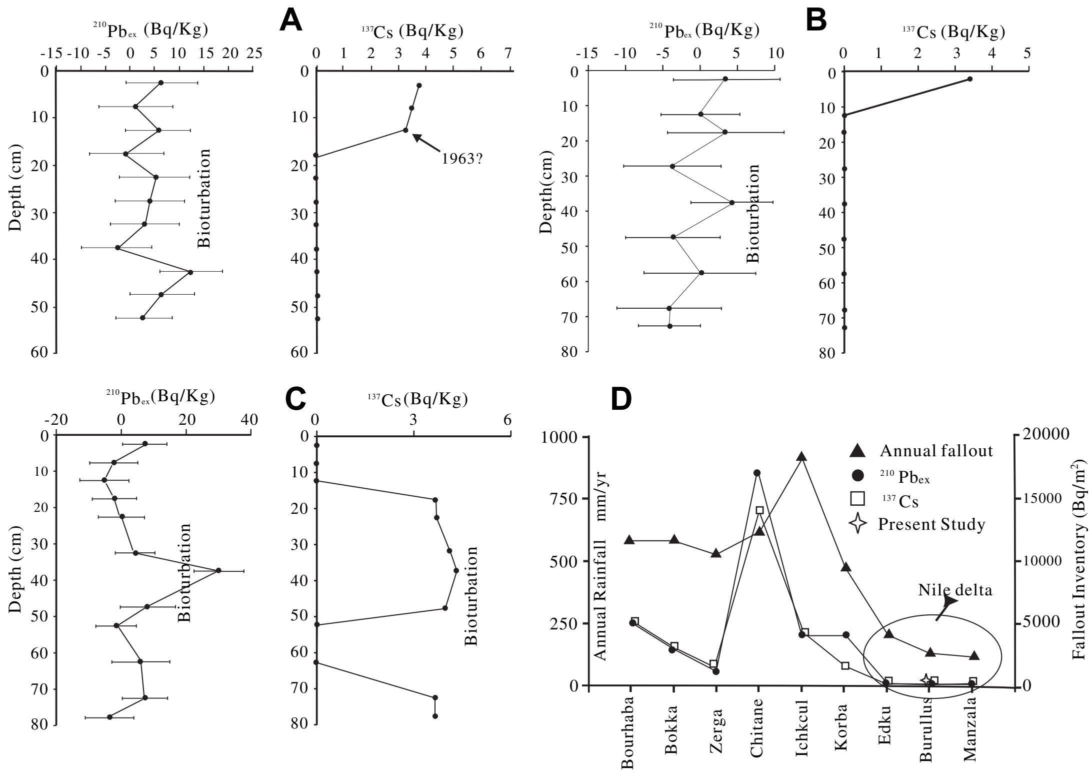

Fig. 3. Downcore distribution of ^{210}Pb and ^{137}Cs in the sediment core B-1 (A), B-2 (B) and B-3 (C); and the annual precipitation and related fallout inventory measured in the southern Mediterranean coasts (D), including the lower Nile coast (modified after Appleby et al., 2001).

12 cm. After normalization, three patterns of heavy metal were identified: 1) Mn, Zn, Ni and Pb showed a large-scale variability below the core depth of 10 cm, but, a general increase toward the core top (Fig. 5B-2-II); 2) Cd and Fe fluctuated below 10 cm, and then stayed stable to the core top and 3) Cu was stable throughout.

5.2.3. B-3

Absolute Cd, Cu, Al and Fe tend to decrease in general from the core bottom to 10 cm, and from there they go up to the core top. Pb remained stable throughout (Fig. 5B-3-I). Zn, Ni and Mn showed variability. Normalization to Al does not help sort out the trend of temporal distribution patterns. Ni slightly goes up until at about 10 cm and Fe seems to reduce its value to about 10 cm, and then turns to higher value, and Cu stayed very stable. Zn increased upward at the 80–15 cm, and then declined, while Pb showed only a minor change (Fig. 5B-3-II).

6. Diagnostic correlation

Correlation of heavy metals, TOM and Clay content (<4μm%) of only the top 10–15 cm part of the core sediments of B-1 and B-2 (Table 1) revealed the diagnostic heavy metals in the study area (note, B-3 is not considered due to unclear trend in the temporal distribution of heavy metals in the upper part of the core sediments). The results demonstrated that Cu, Ni and Al showed significant positive correlation to Fe with coefficients of 0.886, 0.667 and 0.942 (confidence level = 0.05), and Cu and Al correlated positively significantly to Clay with coefficients of 0.794 and 0.678 (Table 1; confidence level = 0.05). Ni and Fe also showed a good affinity to Clay with coefficients of 0.505 and 0.633 (confidence level = 0.05). On the other hand, Mn, Pb and Cd showed negative correlations to Fe (−0.229, −0.489 and −0.316; confidence level = 0.10), and Clay (−0.634, −0.364 and −0.082, but insignificant), but positive correlations to TOM with lower coefficient values (0.029, 0.547 and 0.135). Zn and Fe manifest a positively significant correlation to Clay (0.404 and 0.575; confidence level = 0.05).

7. Discussions and conclusion

7.1. Grain size, TOM and water content

Organic matter that varies in the core sediments of B-1, B-2 and B-3 showed a fairly positive correlation to the sediment grain size, i.e., the finer sediment, the higher the TOM content (A, B, C). Higher TOM in the upper sediments of B-1 and B-2 probably reflects the absorption of pollutants from the sewage outlets nearby and also the accumulation of plant litter (Fig. 1B) (Du Laing et al., 2006). The lower TOM downcore reflects the coarser grain size, which could explain negligible human impact prior to the construction of the Aswan dam. Lower TOM in the upper part of coarser sediment in B-3 may relate to its location away from the sewage outlet.

Higher water content occurs in the upper part of core sediments of 10–15 cm in B-1 and B-2, (Fig. 2 A, B), from where the water content decreased downcore. We assume that the upper 10 cm core sediment in B-1 and B-2 is the product of the post-Aswan dam sedimentation. No similarity is recorded in B-3, which showed sediment coarsening upward, probably due to stronger marine sediment dynamics near the lagoon outlet on the sea coast (Fig. 1B).

7.2. Sedimentation rate

The low activity and irregular depth distribution of ^{210}Pb of the three sediment cores is unable to help determine sedimentation rates (Fig. 3 A, B, C). Appleby et al. (2001) found a similar poor ^{210}Pb

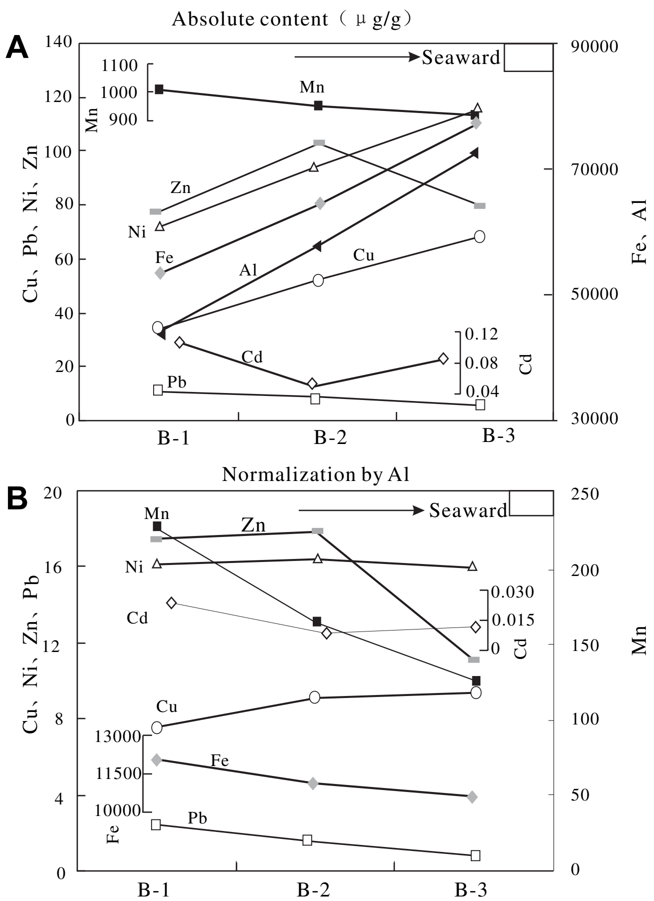

Fig. 4. A) Absolute content of surficial heavy metals in sediment core B-1, B-2 and B-3; and B) Normalized values.

record of the Burullus lagoon with very low inventory of ^{210}Pb of only 240 Bq m^{-2}. They suggested that it can be attributed to the low atmospheric fallout levels arising from the low rainfall in this region (<50 mm/year) (Fig. 3D, see Fig. 3 of Appleby et al., 2001). Bioturbation in the lagoonal setting of the Nile delta, where brackish organisms prevail (Stanley and Warne, 1993), adds further difficulty to radionuclide dating. The sediment lithology of the three cores also contains concentrated shells in the upper core sediment sections (Fig. 2). Bioturbation in coastal sediments largely weakens the applicability of the ^{210}Pb and ^{137}Cs method (Ligero et al., 2005). However, the detectable ^{137}Cs activity above the core depth of 10 cm of B-1 could suggest sedimentation after High Aswan dam emplacement in 1964, assuming that the lowest detectable sample of B-1 at the core depth of about 12 cm refers to nuclear weapon test in 1963 (Fig. 3A).

If so, a sedimentation rate of about 2 mm yr^{-1} can be estimated to account for the top 10 cm core sediment of B1 for the past half century. There could be even lower sedimentation rate of B-2 and B3 after the Aswan High dam, if considering only one detectable sample of ^{137}Cs on the uppermost core sediment (Fig. 3B,C). On the other hand, the higher water content of the upper (10 cm, in general) core sediments may confirm the post-dam sedimentation. Appleby et al. (2001) also estimated the sedimentation rate of about 2 mm yr^{-1} of Burullus lagoon on the basis of ^{137}Cs measurement.

7.3. Diagnostic heavy metals

Fe, Al, Cu, Zn, Mn, Cd, Pb and Ni were selected as the potentially elevated heavy metals in the study area on the basis of the previous results (Saad et al., 1985; Darrag, 1984; Abdel-Moati and El-Sammak, 1997; Birks et al., 2001; Kamal and Magdy, 2005). Normalization to Al (clay content proxy) can minimize grain size effect and help define diagnostic metals in relation to pollution sources of the region (Figs. 4 and 5-A,B,C) (Santschi et al., 2001).

Increasing surficial heavy metals (Mn, Ni, Zn, Fe, Cd and Pb, except Cu) seaward from B-1 to B-3 after normalization apparently evidence the function of distance to the sewerage outlet on the inland lake coast (Fig. 1B). Increasing heavy metals after normalization in the upper part (10 cm above) of the core sediment (B-1 and B-2) also support this observation (Fig. 5B-1-II and B-2-II).

Since Fe can be indicative of terrestrial sediment sources (Windom et al., 1989; Presley et al., 1992; Huang et al., 2003; Wu et al., 2008), those heavy metals with lower coefficient to Fe could imply anthropogenic impact. Heavy metals have also shown its affinity to clay of natural source origin (Zhang and Wang, 2003). The positive and significant correlation of Cu, Ni and Al to Fe and Cu, Al, Ni and Fe to Clay demonstrates a close kinship to terrestrial sources derived from the upstream Nile provenance. The negative correlation of Mn, Pb and Cd with Fe and Clay, but TOM, can be identified as the diagnostic heavy metals in the local pollution sources. Zn in the present study, also positively correlated to Fe, but with lower coefficient (0.0404), is therefore not identified as the diagnostic element of the region (Table 1).

Higher Mn, Pb and Cd are of toxic nature while accumulating (Chen et al., 1985; Chen et al., 2000). The concentrated metals in the upper 10 cm core sediments in Burullus lagoon indicated the recent industrial and agricultural development in the Nile delta plain in the past decades. This timeline can refer to the High Aswan dam constructed in 1964, after which the industrial activities on the coast have boomed rapidly due to economical powers generated (Siegel et al., 1994).

The previous studies have reported that the pollution levels of Burrullus lagoon were relatively low in general when compared to

Table 1
Correlation analysis of heavy metals, TOM and clay. The values are derived from the upper part (<10 cm) of the sediments from B-1 and B-2 cores. Numbers in **Bold** indicate significant correlation (confident level = 0.05).

	Cu	Mn	Ni	Zn	Al	Fe	Cd	Pb	TOM	Clay
Cu	1									
Mn	−0.308	1								
Ni	**0.866**	0.129	1							
Zn	0.564	−0.157	0.542	1						
Al	**0.961**	−0.222	**0.830**	0.520	1					
Fe	**0.886**	−0.229	**0.667**	0.404	**0.942**	1				
Cd	−0.323	−0.596	−0.566	−0.513	−0.368	−0.316	1			
Pb	**−0.729**	−0.018	**−0.878**	−0.377	**−0.683**	−0.489	0.247	1		
TOM	−0.397	0.029	−0.382	−0.196	−0.406	−0.385	0.135	0.547	1	
Clay	**0.794**	−0.634	0.505	0.575	**0.678**	0.633	−0.082	−0.364	−0.371	1

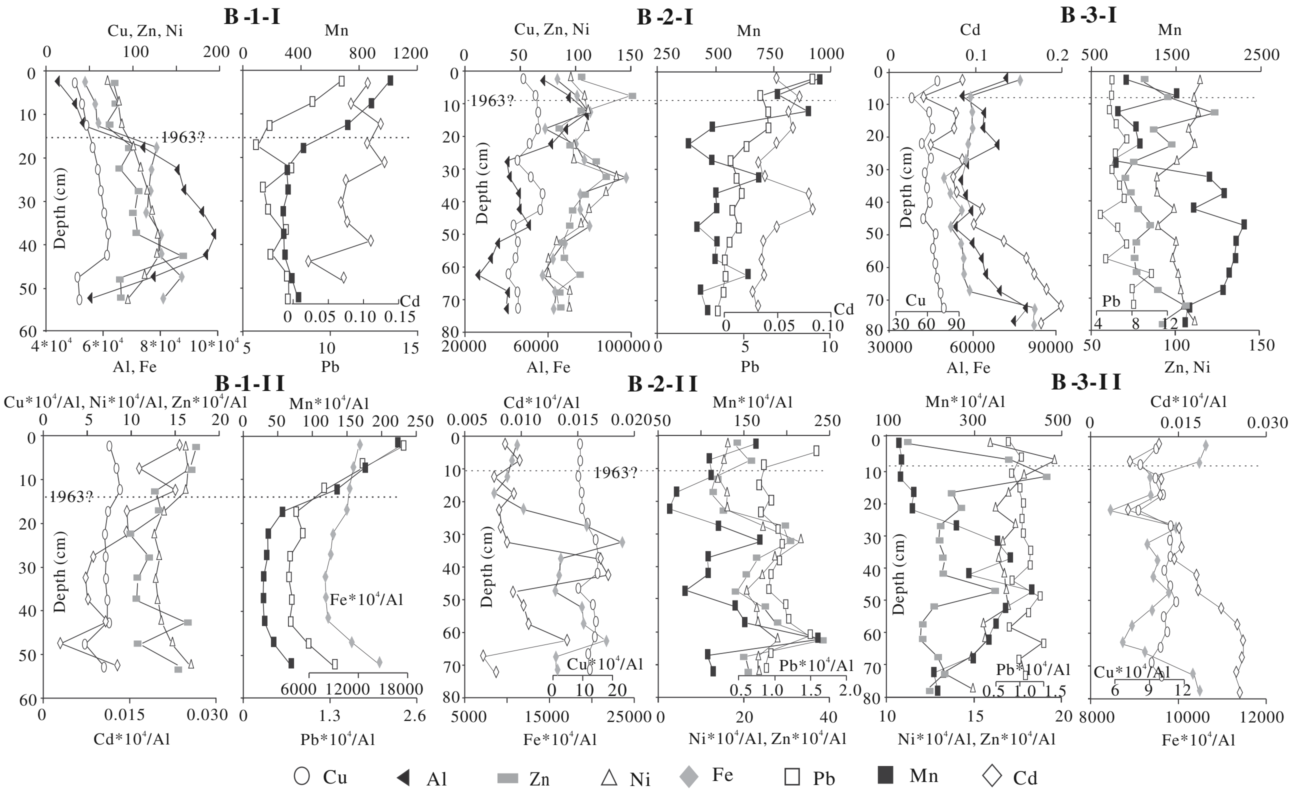

Fig. 5. B-1-I, B-2-I and B-3-I indicating absolute content of heavy metals in three sediment cores; and B-1-II, B-2-II and B-3-II are normalized values for the three cores. Referential year 1963 is assumed on the basis of ^{137}Cs, sediment lithology, and water content.

the other lagoons on the Nile coast (Kamal and Magdy, 2005). The collected heavy metals of the surficial sediments have shown that Pb and Cd in other lakes are much higher than that of Burullus (presented here in absolute values due to unavailability of Al; Table 2). For instance, Cd in Mariut, Iduk and Manzala lagoons are 10.1, 7.3 and 11.8 (μg/g), respectively, while comparing to our result of Cd, i.e. 0.086 (μg/g) averaged from the upper 10-cm sediments in B-1 and B-2, although the earlier study reported 5.2 (μg/g) (Table 2). Pb in Burullus sediments also remained in lower level. However, Mn has shown its higher content than other lakes.

7.4. Ecological remarks

Tanta and Kafrelsheikh are the major downtowns in the central Nile delta plain (Fig. 1A), where over 6 million people live in their governorates. In recent years, wastewaters from industrial and domestic activities are being directly released into Burrullus lagoon in increasing quantities through the canal networks, without any pre-treatment. The rapid rise of petro-refineries and fertilizer manufacturing industries are the major sources of pollution in the region. Accumulated Cd that mirrors geographical clustering of pancreatic cancer risk in the Manzala region of the northeastern Nile coast (Soliman et al., 2006), has not yet been recognized as the major polluting metal in Burullus lagoon, which also serves as the vital aquacultural base in Egypt. Notably, higher Pb and Mn can cause mental, kidney and digestive problems through food chain (Lavery et al., 2009; Neuberger et al., 2009). The present study which highlights the increasing levels of toxic heavy metals such as Mn, Pb and Cd in the Burullus lagoon, calls for concerted efforts towards proper treatment of industrial and domestic effluents prior to releasing into the coastal wetlands in the Nile delta region.

Table 2
Heavy metals of the Nile delta coast – before and after High Aswan Dam (shaded values are diagnostic heavy metals of the present study).

	Sample site (core or surficial sample)	Depth (cm)	Cu (μg/g)	Ni (μg/g)	Zn (μg/g)	Al (μg/g)	Fe (μg/g)	Mn (μg/g)	Pb (μg/g)	Cd (μg/g)
Post-dam (present study)	$B_{-1}+B_{-2}$	10–15 above	48.05	88.94	96.54	55224.78	61449.97	866.5	8.22	0.086
Before-dam (background value; present study)	B-1	15–55	57.52	114.4	103.41	84043.05	79401.39	323.8	6.94	0.082
	B-2	10–75	54.56	101.42	98.41	46945.55	71663.19	531.66	4.62	0.046
	Mean		56.04	107.91	100.91	65494.3	75532.29	427.73	5.78	0.065
Post-dam	Mariut	0–10	574	–	229	–	31900	598	114	10.8
(Data collected from Darrag, 1984;	Mariut	0–20	106.42	242.53	232.74	–	–	–	696.59	10.1
Siegel et al., 1994;	Idku	0–10	19	–	317	–	23600	115	20	7.3
Abdel-Moati and El-Sammak,	Burullus	0–10	16	–	–	–	45000	62	–	–
1997; El-Rayis, 2005)	Burullus	0–10	25	–	90	–	17900	85	14	5.2
	Manzala	0–15	74	–	164	–	35900	847	79	11.8

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