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Distribution and Ecological Risk Assessment of Heavy Metals in Core Sediments of Burullus Lake, Egypt

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ABSTRACT

Burullus Lake is one of the most important coastal deltaic lakes in Egypt. Therefore, this study is focused on the distribution and risk assessment of heavy metals in the lake's core sediments. Seven core sediment samples were taken from seven sites in Burullus Lake. The heavy metals (Mn, Zn, Ni, Cu, Pb, Co, and Cd) content in each core sediment sample were analyzed using Flame Atomic Absorption Spectrophotometer. The mean values of heavy metals in core sediment samples ranged between (4.55 - 7.47), (33.21 - 90.08), (27.42 - 96.40), (81.56 - 389.47), (46.71 - 123.98), (33.48 - 77.08), and (1020.89 - 1326.86) for Cd, Pb, Cu, Zn, Ni, Co, and Mn, respectively. Different sediment indices were calculated to obtain the sediment quality measures and obtain its ecological risk. The mean values of heavy metals followed the decreasing pattern; Mn > Zn > Ni > Cu > Pb > Co > Cd. For enrichment elimination, Mn was used as a reference metal. Enrichment of metals in core samples indicated that Cd was the most abundant, while Cu showed the slightest appearance. The total risk index value was categorized as very high (RI > 380) that may pose risk to aquatic life. Comparison of metal concentrations with sediment quality guidelines is considered. The mean effect range median quotient (mERMq) showed a 21% probability of being toxic at East Burullus surface sediments and a 49% probability of being toxic at other sites. The mean possible effect concentration quotient (mPEC-Q) of metal ions in the sediments of the lake increase with the increasing of depth may be attributed to the accumulation within time. The high percentage of samples increases the sediment quality guidelines SQGs this may cause a hazard to the aquatic organisms in the lake.

INTRODUCTION

The world faces several challenges in all environmental sectors: air, water, soil, and nature. These challenges are mostly as a result of human activities. Egypt is one of the countries likely to be most affected by anthropogenic activities and is intense due to the increase in the local population in Nile Delta (**Warner *et al.*, 2010; Said *et al.*, 2019**). Sediments are important transferors of metal ions in the hydrological cycle and they effectively collect or release metals into the surrounding environments; thus, they can indicate the current quality of aquatic systems (rivers, lakes, and seas) (**Salomons and Forstner, 1984**). During past periods, core sediments study is a beneficial tool for identifying of the natural and anthropogenic processes' effects on deposits of sediments into the environment (**Vinodhini and Narayanan, 2008; Badr *et al*., 2009**). Core sediments can provide chronologies of metal concentrations in sedimentary sequences, and have been used to reveal human effects on the accumulation of heavy metals (**Ma *et al*. 2016)**. The trapped sediments in aquatic systems can potentially become a source of contaminants and pose a threat to biota, funa and water by releasing and disseminating pollutants in the sediment-water interface (**Coynel *et al*., 2007; Audry *et al*., 2010**). Land use/cover activities in the areas around aquatic bodies (as drains or Lakes) play role in the differentiation and distribution of heavy metals in sediments (**El-Alfy *et al.*, 2020a; 2020b).**

Heavy metals (HMs) are less soluble and non-biodegradable elements but usually interact with inorganic and organic materials and later settle down to the bottom sediments of the water body (**Al-Najjar *et al*., 2011**). **Yong et al. and Jiang *et al.* (2017)** stated that wetlands, lakes and lagoons, can be polluted by several types of harmful elements as HMs. The concentration of HMs in water bodies is a critical cause of water pollution and a concern for human health and ecosystems.

Burullus Lake is one of the most important coastal wetlands and considered as a Ramsar site on the northern coast of Egypt. This wetland has an imperious bio-ecological function through offering wide series of ecosystem services and biodiversity. It is located in the middle of the Nile delta and suffering from industrial and agricultural pollutions (**Sheta, 2019**). The wetland is defined by its unique ecosystem with a wide diversity of wetland habitats, varied between freshwater swamps and reed beds in the south, to salt marshes and mudflats in the north. Improving water quality in ecosystems can have significant health, environmental, and economic benefits, especially in terms of low waterborne diseases and heavy metals in sediments (**Ansari *et al*., 2004; Chen *et al*., 2018**). This study aimed at; I) assess the pollution status by determining seven heavy metals content in seven sediment profiles along the shore of Burullus Lake, which considered as a Ramsar site, II) evaluate the sediment quality guidelines in the three cores in each profile at different depths of 10, 20, and 30 cm, and III) suggest recommendations to solve the contamination problem of sediments in those three layers.

MATERIALS AND METHODS

1- Location of Burullus Lake

The Burullus Lake locates at the centr of the coastal northern part of the Nile Delta at Kafr El-Sheikh Governorate. The lake is connected to the Mediterranean Sea at its north-eastern edge through a narrow slit called Boughaz El Burullus. The coordinates of its location are 30° 22`-31° 35`N and 30° 33` - 31° 08`E (Zaid *et al*., 2014). Burullus Lake was registered as a Ramsar site (designated a wetland natural reserve under the

International Ramsar Convention of 1988) and was identified as an important bird area in the year 1998 (**Shaltout, 2010**).

Geomorphology of/around Burullus Lake:

Geomorphologically, the coastal area of the Burullus area can be divided into backshore plain, barrier, a tidal inlet, beach, and deltaic zones. The area indicates numerous landforms characteristic of marine, riverine, and Aeolian processes. These incorporate shore landforms, lake landforms, Aeolian landforms, and riverine landforms (**El-Fayoumy *et al.*, 1993**). The lake is separated from the sea by a narrow barrier to sand and coastal dunes.

2- Sources of core sediments in the lake

Aswan dam has imposed several burdens on Burullus Lake in decades. It has stopped the Nile's sediment deposition process in the delta and Burullus Lake shores. The brackish water of the lake may be as a result of receiving agricultural drainage water from seven drains at the southern part and saline water from El-Boughaz on the north-eastern side.

The bottom sediments of the lake are predominantly structuring less silt clay, with high organic content in parts, and large areas of shelly to silt muddy sand (**Coutlier and Stanley, 1987**). The core sediments of the lake contain allochthonous materials, organic matter, calcareous substances, and diatom silica which generally were deposited in variable amounts at various depths of the cores (**Saad, 1976).**

3- Importance of Burullus Lake and Threats

The Governorate refers to the sustainable development in these recent periods and cleansing operations being occurred to keep the lake. Also, it builded a cornice on the eastern side for protection. Several dredging equipments were found inside the northern part of the lake as a part of an ongoing dredging project held by Kafr El-Sheikh governorate in three stages for deepening and cleaning the lake to a depth ranging from 2m to 7m.

Lake stakeholders used some plant species for different purposes; plants like *Phragmites australis* and *Typha* can be used in industrial sectors as in paper industries. Nearly, the fish production is 55000 tons/year equal to 40 % and 13.5 % productivity of northern lakes and national productivity, respectively (**Soliman *et al.*, 2013**). Fig. 1 indicated the change in the shoreline shape, backfill around the lake and reduction to the inlet of the lake that might be attributed to the sedimentation processes. The lake's importance for economic production and ecological, environmental conservation is threatened by contamination, eutrophication, and different pollutants (heavy metals, pesticides, organic loads …etc.) from drains and other activities around the lake either; fish farms, agriculture, or industries (**Saad, 2003).**

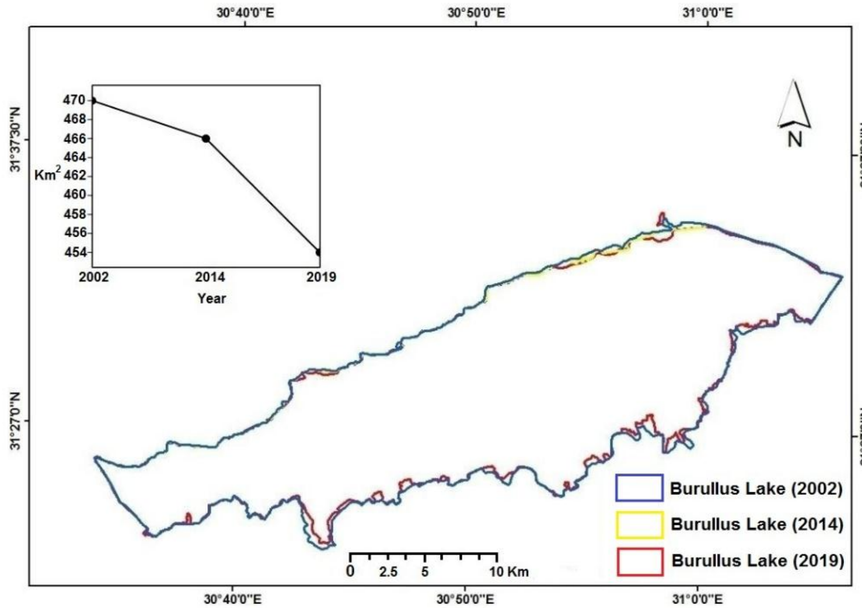

Figure (1) Change of the shoreline of Burullus Lake between different years (2002 – 2019) (Extracted using ArcGIS 10.5)

4- Sampling

In this research, seven core sediment samples were taken from seven sites in Burullus Lake. The selected sites are located in front of the lake's drains and named as follow: East El-Burullus (St.1), El-Boughaz (St.2), Brinbal (St.3), El-Hox (St.4), El-Shakloubah (St.5), Drain 7 (St.6), and El-Khashaa (St.7). Each core sediment sample was cut into three parts (0-10, 10-20, and 20-30 cm). (Figure 2)

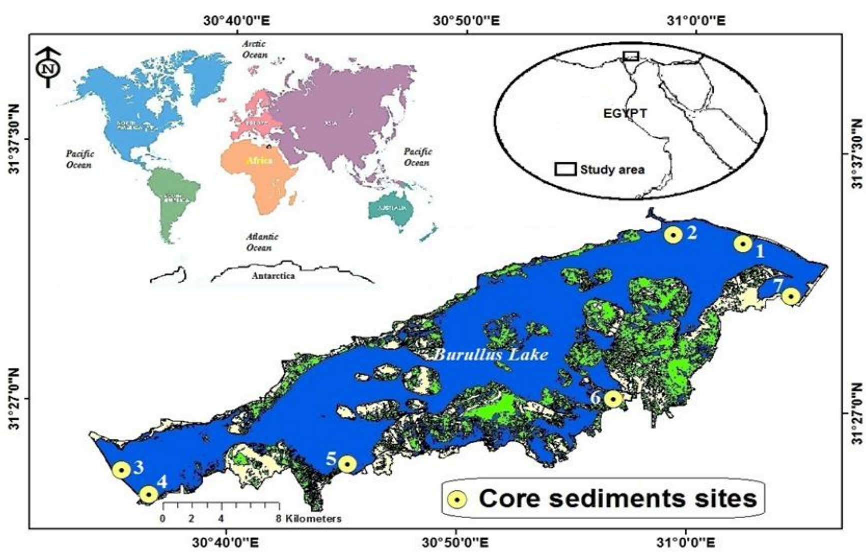

Figure (2) Location of Burullus Lake and sampling sites within it

5- Sediment Analyses

5-1 Hydrogen ion concentration (pH) and Electrical conductivity (EC)

Core sediment pH and EC were measured by using the pH-meter (Model Lutron YK-2001) and EC-meter (YSI Incorporated Model 33) in 1:5 sediment suspensions, respectively, as described by **Jackson (1962).**

5-2 Organic matter (OM)

Organic matter was determined by the loss-on-ignition (LOI) method which involves the heated destruction of all organic matter in the soil or sediment. A known weight of the sample was placed in a ceramic crucible, then was heated between 350° and 440° C overnight (**Blume et al. 1990; Nelson and Sommers 1996; ASTM 2000**). The sample was cooled in a desiccator and was weighed. Organic matter content was calculated as the difference between the initial and final sample weights divided by the initial sample weight times 100%.

5-3 Heavy metals (HM_S)

Heavy metals were determined in dried core sediment samples by Oregioni and **Aston (1984**) technique. The samples were sieved and 0.5 g of the fine fraction (< 0.063 mm) was digested by concentrated nitric, perchloric, and hydrofluoric acids which were added in the ratio of 3:1:2 to the sample in Teflon vessels and was left overnight. The sample was heated to 100 ºC for about two hours, cooled, filtered, and diluted to known measured volume with deionized water. Metals has been determined by Flame Atomic Absorption Spectrophotometer (FAAS Perkin Elmer model AAnalyst 100); the obtained results were expressed in µg/g.

6- Environmental/Eco-toxicological indices

The used indices for the assessment of environmental and eco-toxicological were listed in Table 1 and categories of it as in Table 2.

Table (1) Different used Eco-toxicological indices of heavy metals in core sediments

Index	Formula	Purpose	Reference
Geo-accumulation index (*Igeo*)	$\mathrm{Log}_2\left(\frac{C_n}{1.5B_n}\right)$	explain the metal contamination in sediments	Muller (1969) Chakravarty and Patgiri (2009)
Enrichment factor (EF)	$\frac{M}{Fe}(\mathrm{Sample})/\frac{M}{Fe}(\mathrm{Back\ ground})$	Determine the metal sources	Simex and Helz (1981)
mean Effect Range Median quotient (mERMq)	$\sum_{i=1}^{n}(C_i/ERM_i)/n$	Evaluate the priority of site to being toxic	Long *et al.* (2000)
mean Possible Effective concentration quotient (mPECq)	$\sum_{i=1}^{n}(C_i/PEC_i)/n$	determine the possible biological effect of multiple sedimentary heavy metals	Ingersoll (2001)
Ecological Risk (ER) and Risk Index (Ri)	Tr x CF $\sum_{i=0}^{n}Er$	to assess the degree of heavy metal pollution in sediments	Håkanson (1980)

C: concentration of metal, M: metal, B_n: Background value, PEC: possible effect concentration, Tr: Toxic response, CF: contamination factor and Er: Ecological risk

Table (2) Categories of used indices of heavy metals in core sediments

Index	Categories
I*geo*	≤ 0 unpolluted, 0 < Igeo ≤ 1 unpolluted to moderate, 1 < Igeo ≤ 2 moderately polluted, 2 < Igeo ≤ 3 moderate to strong polluted, 3 < Igeo ≤ 4 strongly polluted, 4 < Igeo ≤ 5 strong to extremely polluted and Igeo > 5 extremely polluted
EF	≤ 1 background concentration, 1-2 depletion to minimal enrichment,2 – 5 moderate enrichment,5–20 significant enrichment, 20 – 40 very high enrichment, > 40 extremely high enrichment
mERMq	Low priority site (≤0.1), medium–low priority site(0.1–0.5), high-medium priority site (0.5–1.5), and high priority site, (>1.5) with a 9%, 21%, 49% and 76% probability of being toxic.
mPEC-Q	Low (< 0.1), moderate (0.1 < mPEC-Q < 1), considerable (1 < mPEC-Q < 5) and very high (mPEC-Q > 5) with < 14%, 15-29%, 33-58% and 75-81% risk, respectively.
Er	Low risk (< 40), moderate (40 ≤ Er < 80), considerable (80 ≤ Er < 160), high (160 ≤ Er < 320), very high (Er ≥ 320).
Ri	Low (Ri < 95), moderate (95 ≤ Ri < 190), considerable (190 ≤ Ri < 380) and very high (Ri > 380).

7- Statistical analysis

At $p < 0.05$, Analysis of variance (ANOVA) was used to determine the mean variation of heavy metal concentrations in sediments within the sampled sites. Principle component analysis (PCA) and cluster analysis were estimated using the PAST program (multivariate statistical package, ver. 1.72).

RESULTS AND DISCUSSION

According to Table 3 and Figure 3, values of pH in dried core sediments solution (1:2.5) of the Burullus lake ranged between 7.33 at 30cm depth of C1 and 8.17 at 20 cm depth of C3. The lowest value was nearby the east side of El-Burullus drain which characterized by the high organic load. The decay of organic matter releases acids into sediments and and leads to decrease in pH (**Chandrakiran, 2013**). The mean highest concentrations of organic matter (96.10%) and electrical conductivity (43.61 ms/cm) were recorded at East El-Burullus station, this is maybe attributed to these reasons; i) the nearby seawater intrusion, ii) the nature of sediments in this station and iii) it is a drain contain agricultural and domestic wastes, this is agreed with **El-Amier *et al.* (2017**).

The average concentration of heavy metals (Mn, Cu, Zn, Ni, Cd, Pb, and Co) in core sediments samples were in this order; Mn > Zn > Ni > Cu > Pb > Co > Cd. The order of those metals in each part of each core sediment sample was represented in Table 3 and Figure 4. It agreed with the results of **Montalvo *et al*. (2014**) who found that Mn is abundant in river sediments in his study and stated that Mn considered essential in marine sediments and constitutes a source of minerals for different flora and fauna marine species. The high levels of manganese at different stations were attributed to the muddy nature of the sediment at these locations (**Darrag, 1984**).

According to ANOVA analysis among mean concentrations of metal ions, it was clear that there was a significant moderate difference for Cu, a significant low difference for Ni, Co, and Pb, and no significant difference for other elements between different sites (Table 3). The core profile was enriched by metals in the following sequences; Cd > Zn > Pb > Co > Ni > Cu. Cd was the most abundant element, while Cu was less enriched in core samples. **El-Amier *et al*. (2017)** found that enrichment distribution of metal ions in bottom sediments followed the decresing patteren Cd > Pb > Zn > Co > Cu > Cr.

Table (3) Metal ions content in core sediments within different sites, One-way ANOVA; Different letters in each treatment mean values significant. ns = not significant at P < 0.05. *: Values are significant at P < 0.05, **: Values are significant at P < 0.01, n=8.

Core	No.	pH	EC	OM	Heavy Metals in µg g^{-1}						
			ms/cm	%	Cd	Pb	Cu	Zn	Ni	Co	Mn
C1	1	ND	84.64	95.24	4.28	31.18	34.40	87.76	52.82	34.50	1032.60
	2	7.99	ND	96.09	4.56	32.74	25.30	76.66	44.93	32.42	1266.24
	3	7.33	2.58	96.96	4.80	35.71	22.55	80.26	42.39	33.51	951.94
	Mean	-	43.61^{a}	96.10^{a}	4.55^{a}	33.21^{b}	27.42^{b}	81.56^{a}	46.71^{b}	33.48^{b}	1083.59^{a}
C2	4	7.75	10.28	94.89	8.53	90.61	75.45	298.89	100.27	72.83	1154.98
	5	7.87	6.94	91.94	6.72	111.79	83.86	283.50	106.68	72.24	1222.55
	6	7.85	8.92	91.25	7.16	67.85	82.19	341.82	123.98	87.83	1307.61
	Mean	-	8.71^{a}	92.69^{a}	7.47^{a}	90.08^{a}	80.50^{a}	308.07^{a}	110.31^{a}	77.63^{a}	1228.38^{a}
C3	7	ND	4.74	91.95	4.73	51.81	41.07	186.49	67.45	49.55	716.04
	8	8.17	2.83	91.80	8.14	87.12	72.51	664.40	121.09	86.11	1316.92
	9	8.13	4.88	92.27	7.35	90.48	54.39	317.52	93.31	70.25	1060.85
	Mean	-	4.15^{a}	92.01^{a}	6.74^{a}	76.47^{ab}	55.99^{ab}	389.47^{a}	93.95^{a}	68.63^{a}	1031.27^{a}
C4	10	7.45	1.63	83.99	4.48	72.70	86.27	245.22	97.44	56.80	638.72
	11	7.72	4.08	85.13	6.92	100.36	117.39	398.31	140.65	91.72	949.01
	12	ND	ND	89.64	7.63	89.53	85.54	218.81	133.85	82.73	1557.00
	Mean	-	2.86^{a}	86.25^{a}	6.35^{a}	87.53^{a}	96.40^{a}	287.44^{a}	123.98^{a}	77.08^{a}	1048.24^{a}
C5	13	ND	2.88	89.12	4.56	70.02	70.83	116.58	87.96	50.64	912.00
	14	7.85	4.44	89.30	4.75	52.67	59.96	174.36	90.07	54.18	896.07
	15	ND	3.28	90.45	6.69	83.34	80.94	172.23	125.34	76.20	1254.60
	Mean	-	3.53^{a}	89.62^{a}	5.33^{a}	68.68^{ab}	70.58^{a}	154.39^{a}	101.12^{a}	60.34^{a}	1020.89^{a}
C6	16	ND	2.42	88.97	5.54	57.70	96.70	221.34	133.65	85.14	1387.54
	17	ND	6.27	92.58	5.03	72.82	68.27	171.24	93.31	59.42	1136.64
	18	8.00	3.52	92.06	6.00	71.40	84.52	214.88	115.52	72.68	1456.40
	Mean	-	4.07^{a}	91.21^{a}	5.52^{a}	67.30^{ab}	83.16^{a}	202.49^{a}	114.16^{a}	72.41^{a}	1326.86^{a}
C7	19	8.05	3.46	90.78	4.11	49.62	54.48	143.34	82.29	52.80	1020.60
	20	8.04	2.42	89.17	6.08	66.04	82.76	249.76	132.48	82.28	1583.60
	21	7.41	5.78	85.04	6.32	108.75	130.62	489.11	146.16	82.19	1126.94
	Mean	-	3.89^{a}	88.33^{a}	5.50^{a}	74.80^{ab}	89.29^{a}	294.07^{a}	120.31^{a}	72.42^{a}	1243.71^{a}
P-Value		0.659^{ns}	0.427^{ns}	0.109^{ns}	0.127^{ns}	0.037^{*}	0.007^{**}	0.105^{ns}	0.012^{*}	0.022^{*}	0.699^{ns}
Reference Value (Turekian and Wedepohl,1961)					0.3	20	95	45	90	19	850

ND: non-detected; for a, b, ab: similar letters indicate no significant difference between the mean values whereas different letters indicate significant difference between mean values.

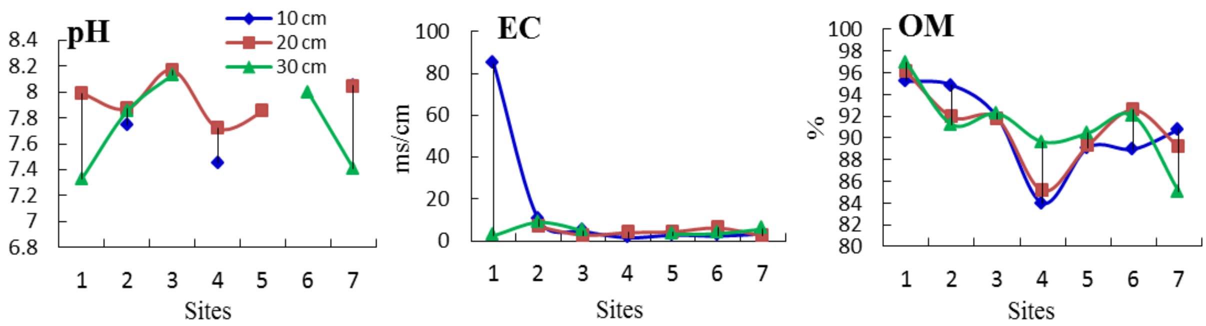

Figure (3) Distribution of pH, EC and OM in core sediments within different sites of Burullus Lake.

From Figure 5 and according to **Liaghati *et al.* (2003**), who indicated that the metal is from crustal materials or natural processes; whereas EF values > 2, we suggested that the sources were more expected to be anthropogenic. So in studied core sediments, it was obvious that the source of Cd in core sediments within different depths was from anthropogenic activities. For Pb, its source was anthropogenic except C1, C6, and C7 at 10 and 20 cm, respectively. While the source of Cu appered to be from natural processes. Zn and Co sources according to EF values at the studied area were also from anthropogenic sources except for C1. The source of Ni was from natural processes.

According to the enrichment factor, cadmium was the most enriched element, while copper showed the lowest appearance. Cd is related to agricultural wastes, pesticides, and fertilizers. These activities are distributed as a result of drains at the southern part of the lake.

For geo-accumulation index, and according to **Buccolieri *et al.* (2006**), classification in Table 2, and results in Fig. 6 the sites were unpolluted by Mn. For Cd, it ranged between unpolluted to moderately polluted at sites 1 and 7 with the first 10 cm and moderately polluted at all depths within all other sites. It was categorized as unpolluted to moderately polluted in all core sediments for Pb, Co, and Zn. For Cu, among core sediments, it varied between unpolluted at site 1 within different depths and unpolluted to moderately polluted at all other sites.

According to sediment quality guidelines SQGs, values of Cd were within ERL, SEL, and higher than other limits of SQG_S. Cores from C2-C7, Cd values were within SEL and higher than other limits. The mean concentration of Pb was higher than ERL, TEL, MET and lower than the other limits. For Cu, concentrations were higher than ERL in cores (C2; C4 –C7). While for TEL, MET, all cores were higher than these limits except in C1.

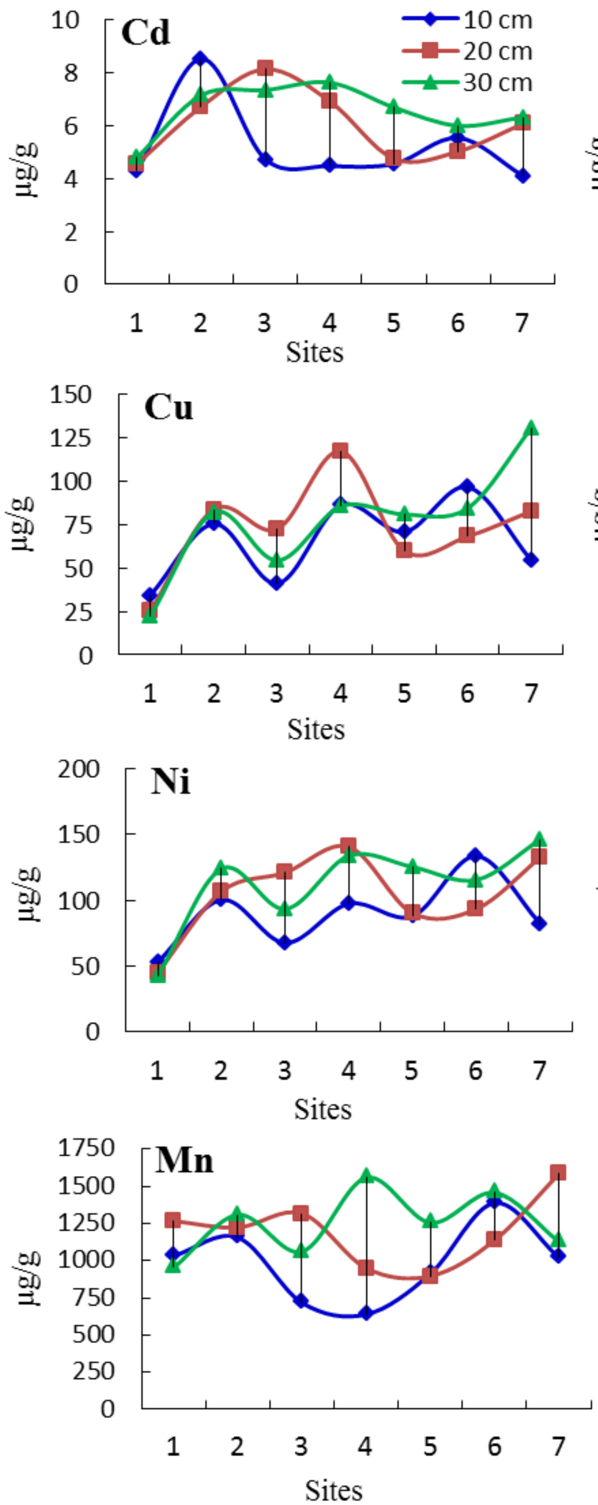

Figure (4) Distribution of heavy metals in core sediments within different sites of Burullus Lake.

For Zn, all core sample concentrations were higher than the limits of ERL, TEL except for C1. And all core samples were higher than ERM except for C1, C6, but for other cores, the recorded mean concentrations within the limit of PEL. Finally, for Ni, the mean concentration of it in core samples was higher than ERL, TEL, MET, and PEL. Also, these cores contain Ni is higher than the limits of ERM, SEL, and TET except C1. Table 4 explained the percent of samples within those limits.

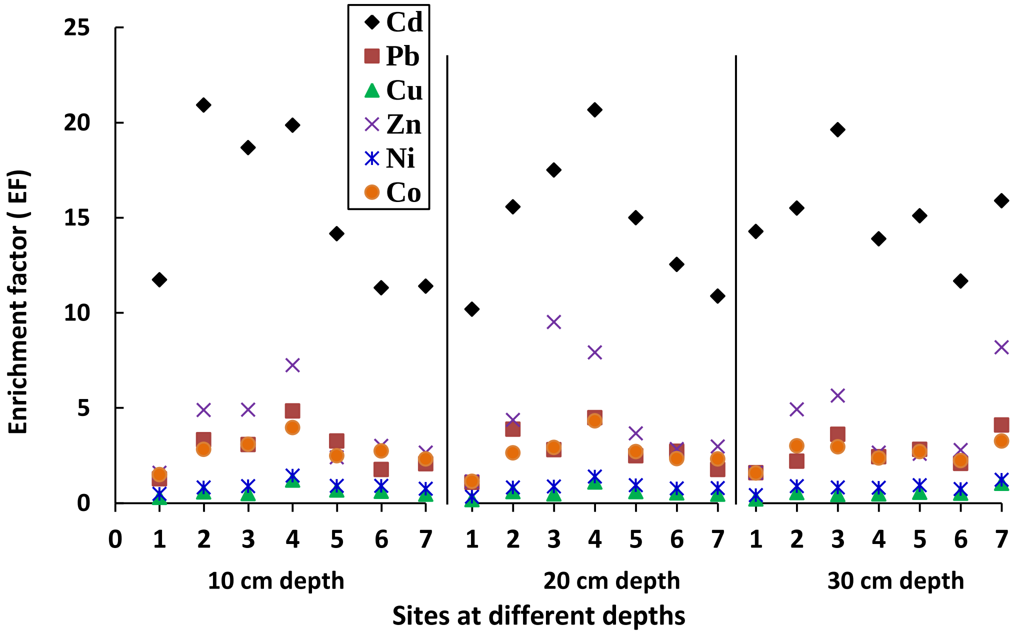

Figure (5) Enrichment factor of heavy metals in the core sediments from different sites along the shore of Burullus Lake.

Ecological risk values were categorized between low for Pb, Cu, Zn, Mn, Co, and Ni; and very high ecological risk for Cd in all sites. **El-Amier *et al.* (2018**) found a high potential risk for Cd in sediments of lake Edku and said that it might be related to different agricultural and industrial wastes. While **El-Alfy *et al.* (2019**) stated that ecological risk of metals in all sites of the studied environments (Rosetta and Marine environments) were in the low potential ecological risk category of surface sediments (< 40).

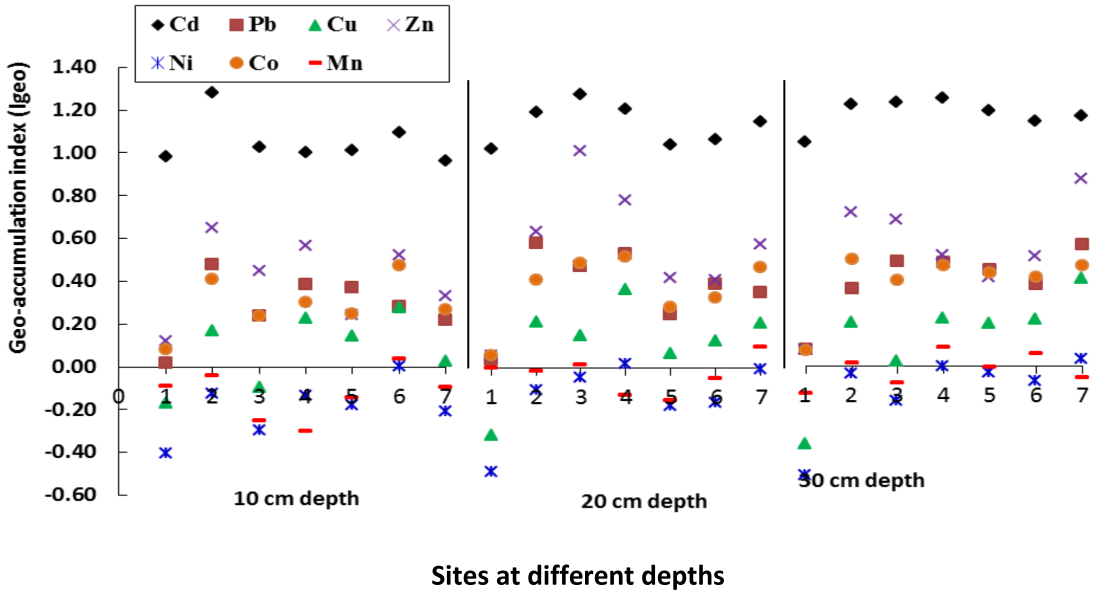

Figure (6) The geo-accumulation index (I*geo*) of heavy metals in the core sediments from different sites along the shore of Burullus Lake.

Table (4). Sediment quality guidelines SQGS (MacDonald *et al*., 2000) and comparison with samples range.

SQGs and % samples > SQGs	Cd	Pb	Cu	Zn	Ni
Effects Range Low (ERL)	5	35	70	120	30
% S > ERL	61.90	90.48	57.14	80.95	100
Threshold Effect Level (TEL)	0.6	35	35.7	123	18
% S > TEL	100	90.48	85.71	80.95	100
Minimal Effect Threshold (MET)	0.9	42	28	NA	35
% S > MET	100	85.71	90.48	NA	100
Effects Range Median (ERM)	9	110	390	270	50
% S > ERM	0	4.76	0	33.33	90.48
Probable Effect Level (PEL)	3.53	91.3	197	315	36
% S > PEL	100	14.29	0	23.81	100
Severe Effect Level (SEL)	10	250	110	NA	75
% S > SEL	0	0	9.52	NA	80.95
Toxic Effect Threshold (TET)	3	170	100	NA	61
% S > TET	100	0	9.52	NA	85.71
Threshold Effect Concentration (TEC)	0.99	35.8	31.6	121	22.7
% S > TEC	100	85.71	9.52	80.95	100
Possible Effect Concentration (PEC)	4.98	128	149	459	48.6
% S > PEC	61.90	0	0	9.52	90.48

% S: % Samples & SQGs: Sediment qualiy guidelines

As a result of the high ecological risk values of Cd, the total risk value (Ri) was categorized as very high. Also, the risk index for single samples at different depths was found to be very high in 100% of samples (Table 5). **Niu *et al.* (2015**) stated that metals with significantly higher RI levels may pose a high ecological risk to Lake's ecosystem.

The calculation of mPEC-Q indicated that 71.43% and 28.57% of core sediment samples at depth 10 cm were found to be moderate to considerable risk with 15-29% and 33-58%, respectively (Fig. 8). At core sediments of 20 cm, nearly 42.86 and 57.14% of samples showed moderate to considerable risk, respectively. While, at core sediments with 30 cm, the mPEC-Q results indicated that 14.29 and 85.71% of samples were moderate to considerable risk with 15-29% and 33-58% risk, respectively. These results indicated that the possible effect concentration of metal ions in the sediments of the lake increased with the increasing of depth and this is may be attributed to the accumulation within time. It was also clear that the high percent of moderate risk that has been observed at the first core may attributed to the cleansing processes in the lake.

From mERMq, site 1 was medium to low priority site with only 21% probability of being toxic in the core samples of 10 cm (represented at 14.29% of core samples), this is may be attributed to the seawater intrusion. While other cores in all depths within all sites showed high to medium priority sites with a 49% probability of being toxic (represented by 85.71% of core samples) (Figure 7).

Table (5) Average values of ecological risk (Er) and risk index (Ri) of each core within sites

Core No	Er							Ri
	Cd	Pb	Cu	Zn	Ni	Co	Mn	
C1	454.53	8.30	1.44	1.81	2.60	8.81	1.27	478.77
C2	746.97	22.52	4.24	6.85	6.13	20.43	1.45	808.57
C3	673.83	19.12	2.95	8.65	5.22	18.06	1.21	729.05
C4	634.50	21.88	5.07	6.39	6.89	20.28	1.23	696.25
C5	533.20	17.17	3.71	3.43	5.62	15.88	1.20	580.21
C6	552.47	16.83	4.38	4.50	6.34	19.06	1.56	605.13
C7	550.40	18.70	4.70	6.53	6.68	19.06	1.46	607.54

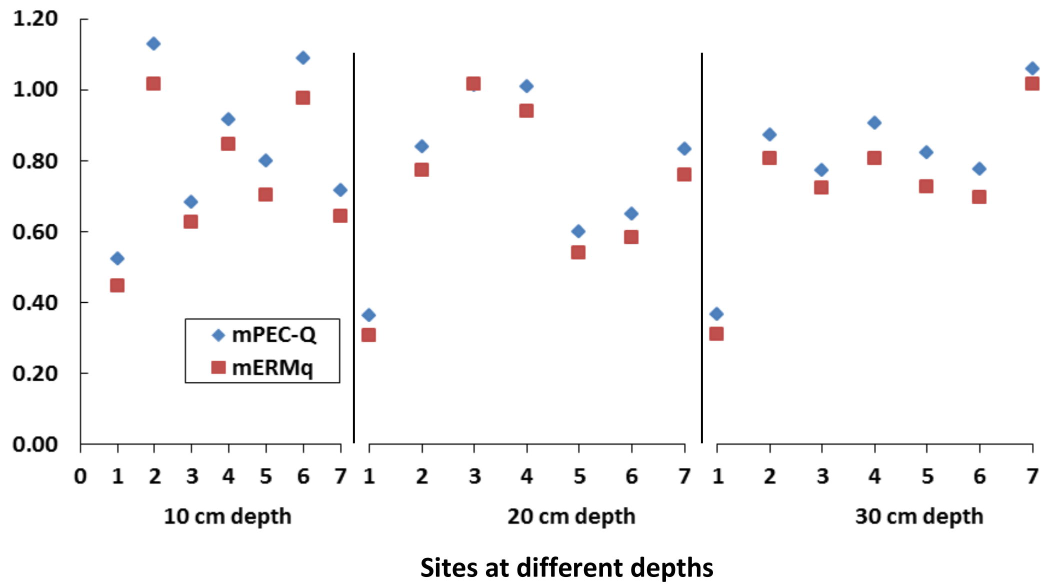

Figure (7) mPEC-Q and mERMq of heavy metals in the core sediments from different depths along the shore of Burullus Lake.

Cluster analysis has been used to identify the similarity groups between the sampling sites. It was performed using the mean of raw data of metal ions. **Alkarkhi *et al.* (2009**) stated that cluster analysis has many benefits; i) rapid assessment of heavy metals as only a site of each group may represent it, ii) design future spatial sampling strategies, and iii) maintain the sampling number. So it can aid in maintaining cost without loss of importance of studies. The CA in this research indicated the similarity of sites 3 and 4 in the western corner of the lake. Sites 1 and 5; 2 and 7 of waste similarities were ranked between wastewater from agricultural, domestic, and sewage wastes (Fig. 8).

From PCA as in Fig. 8, the first two axes PC1 and PC2 explained (63.4% of data). The correlation between Mn and OM within site 1, especially at the depth of 10 cm, might be attributed to the recent accumulation of OM on the surface of sediments from East El-Burullus drain also might be correlated with EC as a result of the seawater intrusion in this area. Organic matter can adsorb metal ions from sediments (**Damak *et al*., 2019**). Co showed positive correlation within sites 4 and 5 represented El-Hoks and El-Shakhlouba areas. Cd was related to the first 10 cm of sediments nearby El-Boughaz and this is may be related to sludge contain domestic wastewater that was released from the wastewater treatment plant in Burg El-Burullus City and accumulated in the sediments of this area. Domestic sewage is one of the major sources of Cd (**Huzinger, 1980**). Metals positively correlated with each other seem to be from similar sources (**Dan *et al.*, 2014**). Cd, Co, and Pb may be attributed to the use of phosphatic fertilizers (**Mohamed *et al*., 2004**). **Okazaki and Saito (1989**) revealed that discharge of Cu and Zn in sediments influenced by anthropogenic activities.

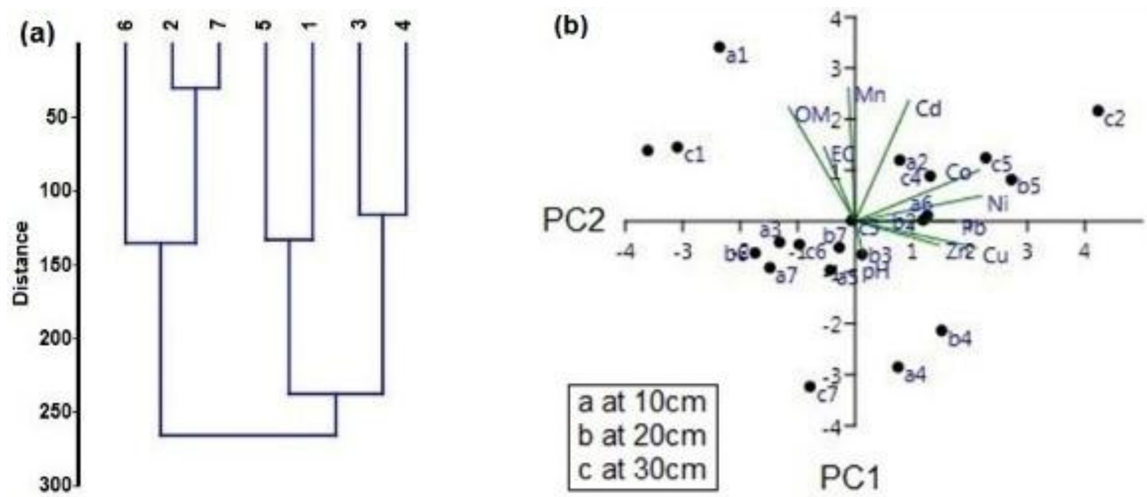

Figure (8) [a] Cluster analysis (CA) among different sites based on mean concentration of heavy metals data ,and [b] Principle component analysis (PCA) between metal ions concentrations at different depths within sampling sites.

CONCLUSION

Burullus lake is a Ramsar site in Egypt. The study revealed a high content of HMs in its core sediments. Cd was the most abundant and enriched element as a result of different industrial and agricultural wastes. the mPEC-Q indicated risk with the increase of depth. A high percentage of samples leaded to increase of the SQGs thus, might cause a hazard to the aquatic organisms in the lake. Dredging and cleansing processes are beneficial to keep the lake and biodiversity. So we recommend a management strategy to serve the biodiversity of the Burullus Lake and preserve its economic importance. As inefficient treatment accumulate sludge with a high concentration of toxic metals into surface sediments of the lake, we also recommend some points that can be considered as using treatment plants before drainage wastes into the lake; removing unwanted, dead aquatic plants before deposition into sediments, and enhancing the treatment efficiency of WWTP before discharge into the lake. From other side, the government did a safety belt around the lake to prevent the encroachment and dredging processes in El-Boughaz and other areas of the lake and recommended the sustainable development of the northern lakes.

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الملخص العربي

توزيع وتقييم المخاطر البيئية للمعادن الثقيلة في الرواسب الأساسية لبحيرة البرلس ، مصر

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تم تحديد محتوى العناصر الثقيلة في الرواسب الاساسية لبحيرة البرلس بالاضافة لتقييم المخاطر البيئية لهذه العناصر. تم جمع عدد 21 عينة من 7 مواقع لقطاعات تتراوح ما بين 10، 20 و 30 سم بطول خط الشاطئ للبحيرة. ومن ثم تم تعيين محتوى العناصر الثقيلة في العينات. متوسط القيم لهذه العناصر كان كالتالي: 5.92، 71.15، 71.90، 245.36، 101.51، 66 و 1140.42 للكادميوم، الرصاص، النحاس، الزنك، النيكل، الكوبلت و المنجنيز على التوالي. تم استخدام مدلولات للرواسب لحساب وقياس جودتها والخطورة البيئية لهذه المعادن. وكان ترتيب العناصر في هذه الرواسب كالاتي: المنجنيز > الخارصين > النيكل > النحاس > الرصاص > الكوبلت > الكادميوم. ولتعيين الوفرة بالمعادن الثقيلة في هذه الرواسب تم استخدام المنجنيز كعنصر مرجعي. وأوضح معامل الوفرة ان الكادميوم كان أكثر العناصر وفرة على عكس النحاس الاقل وفرة. كانت قيمة معدل الخطورة عالية جدا مما قد تؤثر على الحياة البحرية. مقارنة تركيزات العناصر مع معدلات جودة الرواسب تم اخذها بالاعتبار. حيث أن متوسط مدى التأثير اوضح 21% احتمال للسمية بموقع شرق البرلس و 49% للمواقع الأخرى. كما أن النتائج أوضحت زيادة متوسط تركيز التأثير المحتمل لأيونات المعادن في رواسب البحيرة مع زيادة العمق ربما لتراكمها مع الوقت. كما أن نسبة عالية من هذه العينات زاد تركيزها عن الحدود المسموح بها مما قد يسبب خطورة للكائنات الحية بالبحيرة. عمليات التطهير والتكريك قد تكون مفيدة للتخلص من هذه الرواسب ذات المحتوى العالي من العناصر الثقيلة والحفاظ على البحيرة من التلوث.