FULL LENGTH ARTICLE

Metal pollution assessment in the surface sediment of Lake Nasser, Egypt

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Abstract Eight heavy metals were measured seasonally in the sediment of Lake Nasser during 2013. 27 sites were chosen through 9 sectors across the main channel of the lake from Abu-Simbel to Aswan High Dam to assess the levels of the selected metals. The abundance of these metals was in the order of Fe > Mn > Zn > Cr > Ni > Cu > Pb > Cd, with mean concentrations of 12.41 mg/g, 279.56, 35.38, 30.79, 27.56, 21.78, 11.21 and 0.183 µg/g, respectively. Heavy metals are positively correlated with fine particles (mud fractions) and organic matter accumulation. The results showed perspicuous spatial high significant differences ($P < 0.01$) for all the measured metals. Fe, Cr, Ni, Pb and Cd exhibited temporally high significant differences ($P < 0.01$) before and after the flood period. Four Pollution Indices were used for the environmental assessment of Lake Nasser sediment. The indices included three single indices, Enrichment Factor (*EF*), Index of Geo-accumulation (I_{geo}) and Contamination Factor (*CF*). While the fourth, Pollution Load Index (PLI) was an integrated index. The pollution indexes confirmed that the Lake Nasser sediment was not contaminated with these elements. Sediments of Lake Nasser may be represented as a reference for the pre-industrial background of River Nile Sediments downstream Aswan High Dam.

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Introduction

Lake Nasser is very vital to Egypt; it provides more than 95% of the Egyptian freshwater budget. It has a long and narrow shape particularly at its southern part Lake Nubia (Elshemy, 2010). The huge amounts of the Sudanese Nile water have been stored and large volumes of sediments have accumulated today in reservoirs that are trapped (settled) behind the High Dam

due to the sudden reduction in the velocity of the Main Nile upon meeting the new born Lake (Darwish, 2013).

Trace metals enter the aquatic environment from both natural and anthropogenic sources. Entry may be as a result of direct discharges into both freshwater and marine ecosystems, or through indirect routes such as dry and wet deposition and land runoffs. Important natural sources are volcanic activity, continental weathering and forest fires (Biney et al., 1992).

Sediments play an important role in elemental cycling in the aquatic environment. They are responsible for transporting a significant proportion of many nutrients and contaminants. They also mediate their uptake, storage, release and transfer

between environmental compartments. The release of trace metals from sediments into the water body and consequently fish will depend on the chemical fractionation of metals and other factors such as sediment pH, the physical and chemical characteristics of the aquatic system (Morgan and Stumm, 1991; Uzairu et al., 2009).

Most sediments in surface waters are derived from surface erosion and comprise a mineral component, which arises from the erosion of bedrock. They may also comprise and an organic component, which arises during soil-forming processes (including biological and microbiological production and decomposition). An additional organic component may be added by biological activity within the water body (Ongley, 1996). Sediments are important sinks for various pollutants like trace metals. They can also act as a nonpoint source and have the potential to release the sediment-bound metals and other pollutants to overlying waters, and in turn adversely affect aquatic organisms (Wang et al., 2010). The contamination levels of the aquatic environment by heavy metals can be estimated by analyzing water, sediments and marine organisms (El Nemr et al. 2012).

Heavy metals are usually present at low concentrations in aquatic environments but deposits of anthropogenic origin have raised their concentrations, causing environmental problems in lakes (Ntakirutimana et al., 2013). According to Mohamed (2005) the highest concentrations of heavy metals in sediment may be related to the terrigenous input and anthropogenic influence. The high content of trace metals in the sediments can be a good indication of man-induced pollution and high levels of heavy metals can often be attributed to terrigenous input and anthropogenic influences, rather than natural enrichment of the sediment by geological weathering (Mohamed, 2005).

An associated geochemical process plays an important role in the deposition of trace and heavy elements from the water column to the bottom sediments (Ali and Dzombak, 1996; Tessier et al., 1996). Heavy metals are non-biodegradable; they are not removed from water as a result of self purification. Once they are discharged into water bodies, they are adsorbed on sediment particles, accumulate in reservoirs and enter the food chain (Loska and Wiechula, 2003). Fish may absorb dissolved elements and heavy metals from surrounding water and food, which may then accumulate in various tissues in significant amounts (El-Saieed and Abdel-Wahed, 1995).

Variety of methods have been developed for the risk assessment of heavy-metals in sediment as sediments enrichment factor, index of geological accumulation and pollution load index. Various elements have different toxicological effects, among which some are highly toxic and others slightly toxic (Sun et al., 2010). Ecological risk management provides policy makers and resource managers as well, as the public, with systematic methods that can inform decision making. A number of studies have applied this method (Serveiss, 2002; Ohlson and Serveiss, 2007).

The main source of heavy metals in Lake Nasser is the suspended and dissolved solids which are carried by water due to the land degradation in watersheds of River Nile Basin especially from Ethiopian Highlands (Ahmed and Ismail, 2008).

The High Dam Lake acts as a sink for particles/elements (particularly in Sudanese sector) from various sources including the surface runoff, groundwater, waste outlets, and atmospheric deposition that are the main pathways of trace element which are transported to the lake ecosystem. Fishing boats, cruise ships and some agriculture activities represent the main anthropogenic sources of heavy metals in Egyptian Lake Nasser. The study of heavy metal content in Lake Nasser sediment was the focus of many authors (El-Dardir, 1984; Lasheen, 1987; Elewa, 1980; Elewa and Latif, 1988; Elewa et al., 1990; Moalla and Ismail, 1996; Moalla, 1997; Moalla et al., 1998; Heikal, 2008; Goher and Ali, 2009; Abou El Ella and El Samman, 2010; Yousry, 2011; Darwish, 2013).

The main objective of this study is to evaluate the sediment quality of Lake Nasser according to the content of heavy metals and the effect of environmental conditions on it. Ecological risk index was assessed to study the sediment pollution status of heavy metals in Lake Nasser which give an insight into decision-making for water source security (Ntakirutimana et al., 2013).

Geological settings

The area of Lake Nasser belongs to the so-called Arabo-Nubian Massif. The area is characterized by four main geomorphological and geological units. These are: Aswan Hills, old Nile Valley and High Dam Reservoir, Lake Nasser, Nubian Plain, and Sinn El-Kaddab Plateau. The Aswan Hills extend along the eastern bank of Lake Nasser and are characterized by their rugged topography. Precambrian basement rocks are exposed within the hills along the crust of the uplifts (Issawi, 1968).The old Nile valley and the High Dam reservoir are located along the western edge of Aswan hills. Lake Nasser extends mostly over the low lands in the west of the old Nile valley.

The Nubian Plain covers most of the low lands west of the old Nile valley. It has a relatively flat surface covered by Foreland sediments, ranging in age from Late Cretaceous to Eocene. These sediments overlie the Pre-Cambrian rock unit.

Lake Nasser area is characterized by three main features (Issawi, 1968, 1978). The most important one is faulting. The largest of which are Kalabsha and Seiyal Faults, trending mainly in an E–W direction. Faults in the N–S direction are also predominant. Two other systems of subordinate faults, the NW–SW and the NE–SW also exist. The area is affected by up-arching due to the uplifting of basement rocks. Folding is a less predominant structure. Small domes and several basins were created according to the up-arching of the basement.

Materials and methods

Study area

Egypt is preoccupied with a shortage of water resources in addition to an increase in population and the adoption of economic development projects. The Nile River is the principal artery of life in Egypt. It is life itself (Hassan and Al Rasheedy, 2007). The AHD (or Lake Nasser) reservoir is situated in a desert area which is in the transition zone between the subtropical climate and the Mediterranean climate (arid and semi-arid). Lake Nasser represents a central water bank of Egypt and is one of the longest man-made lakes in the world which was formed after the construction of Aswan High Dam in 1964, and was completed in 1970.

The current length at 180 m over mean sea level is about 500 km, of which 350 km are within the Egyptian territory

and are known as Lake Nasser (between 22°00′–23°58′ N and
31°19′–33°15′ E). The 150 km stretch which lies in the northern
part of Sudan is known as Lake Nubia (between 20°27′–
22°00′ N and 30°07′–31°19′ E) (Abou El Ella and El
Samman, 2010; Elshemy, 2010). The total surface area is
6276 km² (5237 km² as Lake Nasser and 1039 km² as Lake
Nubia) at 180 m over mean sea level (MSL) (Abou El Ella
and El Samman 2010; Heikal, 2010). The lake shoreline is very
irregular with numerous side channels known as khors. The
lake is divided into three sections, firstly, a riverine section,
with all-year riverine characteristics, comprised of the southern
part of Lake Nubia from the southern end to Daweishat. Sec-
ondly, the semi-riverine section, with riverine characteristics
during the flood season and lacustrine conditions during the
rest of the year; it comprises the north part of Lake Nubia
and the south part of Lake Nasser. It extends from Daweishat
to Amada/Tushka. Finally, the lacustrine section which
extends from Amada–Tushka to the dam (El Shabrawy, 2009).

Sediment samples were surveyed during 2013. Samples were
collected from 9 sectors in the main channel of the lake from
north to south; High Dam, Dahmit, Kalabsha, Wadi-Abyad,
El-Madiq, Korosko, Amada, Tushka, and Abu-Simbel,
respectively; three sites in each sector were selected (eastern
and western banks in addition to the middle of the main
channel) (Fig. 1).

Sampling

This work was undertaken through a comprehensive program
of the National Institute of Oceanography and Fisheries
(NIOF) (Fresh Water and Lakes Division-FWLD) in order
to study the recent environmental conditions of Lake Nasser.
The sampling program was done during 2013.

Figure 1 The selected sectors in the Egyptian Lake Nasser
(general location of the Lake in Egypt is shown in the top left
corner).

Surface sediment samples were collected seasonally of bot-
tom sediments which were quickly packed in air tight poly-
thene bags. Then, subsamples of the sediments were oven
dried at 105 °C to constant weight and were grinded using
mortar and pestle. Later the samples were sieved to ⩽120 μm.

Procedure

Sediment samples were prepared by using decantation method,
Grain size analysis was conducted by the dry sieving technique
(Folk, 1980). Samples containing more than 5% fine fraction
(finer than 4Ø) were analyzed using the pipette method as
described by Griffiths (1951) and Carver (1971). Sediment tex-
tural classes were deduced according to Folk (1980).

pH and the electrical conductivity (EC) in sediments were
measured by using Thermo Orion Star (A 329 multi-parame-
ters). The pH was measured in 1:2.5 sediment to distilled water
ratio; the suspension was left to stand overnight prior to the
pH determination. The electrical conductivity (EC) was mea-
sured in the saturation extract of the sediments. Organic mat-
ter was carried out according to Nelson and Sommers (1996)
by titrimetric method.

For heavy metal determination, complete digestion of sed-
iment was done according to Kouadia and Trefry, 1987. Equal
amounts (15 ml) of concentrated nitric acid, hydrofluoric acid
and perchloric acid were added to 0.5 g of the finely ground
sediment material into Teflon beaker. Teflon beakers were cov-
ered and set aside for several hours, then evaporated to a few
drops. Then 5 ml of $HClO_4$ was added again and evaporated
to dryness. Concentrated HCl (10 ml) was added to each sam-
ple and the beakers were then placed back on a hot plate until
the solution was clear and the fumes ceased. Deionized dis-
tilled water was added and the digested material was filtered,
then the residue was washed several times with deionized dis-
tilled water and complete to 100 ml volumetric flask. Fe,
Mn, Zn, Cu Cr, Ni, Pb and Cd were analyzed by atomic
absorption model GBC SavantaAA AA with GF 5000 graph-
ite furnace.

Statistics

Means and standard deviations were reported when
appropriate. One-way ANOVA analysis, followed by a post
hoc comparison using Tukey's test, were applied to identify
significant differences in measured parameters among
sampling points. ANOVA tests were carried using IBM SPSS
Statistics 20 software package. Pearson's correlation analysis
was performed to evaluate potential relationships among the
different variables.

Pollution index

Four Pollution Indices were used for the environmental assess-
ment of Lake Nasser sediment (Table 1). The indices included
three single indices: Enrichment Factor (EF), Index of
Geo-accumulation (I_{geo}), and Contamination Factor (CF),
while the fourth; Pollution Load Index (PLI); is integrated
indices (Qingjie and Jun, 2008). These indices are used to assess
heavy metal contamination in sediment. It is necessary to com-
pare the level of studied metals in lake sediments with the pre-
industrial reference level. But in our study the composition of

Table 1 Terminologies for pollution classes on single and integrated indices.

EF classes[a]		Cf classes[b]		I_geo classes[c]			PLI[d]	
EF value	Pollution	CF value	Pollution	I_{geo}	I_{geo} class	Pollution	PLI	Pollution
EF < 2	Depletion to mineral	CF < 1	Low	<0–0	0	Unpolluted	0	Perfection
2 ⩽ EF < 5	Moderate	1 ⩽ CF ⩾ 3	Moderated	0–1	1	Unpolluted to moderated	<1	Baseline levels
5 ⩽ EF < 20	Significant	3 ⩽ CF ⩾ 6	Considerable	1–2	2	Moderated polluted	>1	Polluted
20 ⩽ EF < 40	Very high	CF > 6	Very high	2–3	3	Moderated to high polluted		
EF > 40	Extremely high			3–4	4	Highly polluted		
				4–5	5	Highly to extremely polluted		
				5–6	>5	Extremely polluted		

[a] According to Sutherland (2000).
[b] According to Gong et al. (2008).
[c] According to Buccolieri et al. (2006).
[d] According to Tomlinson et al. (1980).

upper continental crust (UCC) was used as a representative of pre-industrial reference level of trace/heavy metals.

Results and discussion

Grain size and physicochemical analysis

Sediment fractions' texture, pH, EC, and organic matter contents of Lake Nasser sediments are given in Tables 2 and 3.

Sand fraction varied from a maximum value of 94.83% at the western bank of High Dam sector during winter, and was not recorded at many sectors during four seasons. Gravel fraction is not recorded except at Dahmit sector with 100% and 21.37% during spring and winter, respectively. Mud fraction varied between maximum value of 100% at main channel of many sectors during four seasons and minimum value 1.53% at the western bank of High Dam sector during summer. Silt and clay fractions varied between 85.30% at Korosko sector during autumn and 90.33% at Abu-Simbel sector during autumn, respectively; both not recorded at the western bank of Dahmit sector. The results agreed with those obtained by Smith, 1978; El-Dardir 1984; 1987; 1994; Iskaros and El Dardir, 2010, who stated that most of the main channel sediments are clayey sediments, and that the maximum sedimentation takes place at Adindan and Abu Simbel (in the southern

Table 2 Fractions ratios of Lake Nasser sediments and their texture during 2013.

Site	Gravel	Sand	Silt	Clay	Mud	Sediment type
1	0 (0–0)	78.12 (45.65–92.35)	20.08 (2.76–28.74)	11.80 (3.96–17.77)	31.88 (18.62–47.02)	Muddy sand
2	0 (0–0)	22.79 (45.59–0)	28.09 (26.11–30.07)	49.11 (24.33–73.88)	77.20 (54.40–100)	Muddy sand
3	0.53 (0–2.07)	85.48 (54.28–98.40)	9.29 (0–33.98)	6.84 (1.95–11.73)	13.98 (1.52–45.71)	Muddy sand
4	0 (0–0)	40.16 (0–60.2)	36.12 (22.27–57.59)	20.78 (8.73–42.40)	59.83 (39.74–100)	Muddy sand
5	0 (0–0)	4.48 (0–13.45)	42.78 (27.72–53.93)	52.73 (39.86–72.27)	95.51 (86.55–100)	Muddy sand
6	30.34 (0–100)	59.45 (0–83.26)	6.19 (0–11.54)	4.23 (0–9.20)	10.2 (0–18.33)	Muddy sand
7	75.51 (95.71–55.31)	20.94 (0–41.88)	*****	*****	3.54 (2.79–4.28)	Muddy gravelly sand
8	0 (0–0)	52.92 (33.94–70.79)	28.23 (20.69–32.89)	21.08 (8.51–33.16)	47.07 (29.21–66.05)	Muddy sandy gravel
9	0 (0–0)	59.41 (39.69–73.27)	22.44 (16.58–26.58)	25.84 (18.14–36.13)	40.58 (26.72–60.30)	Muddy sand
10	0 (0–0)	59.67 (32.65–69.53)	28.57 (21.07–33.21)	11.74 (2.11–21.51)	40.32 (25.62–59.24)	Muddy sand
11	12.08 (19.65–0)	29.84 (19.91–37.07)	33.19 (23.76–42.57)	24.88 (10.02–39.73)	58.07 (43.26–67.46)	Muddy sand
12	10.26 (30.78–0)	16.49 (0–26.82)	45.85 (20.05–75.10)	37.65 (22.34–55.68)	73.24 (42.39–100)	Gravelly sandy mud
13	0 (0–0)	74.44 (43.33–68.21)	19.43 (8.34–48.43)	6.11 (5.23–7.01)	25.55 (11.02–40.22)	Gravelly sandy mud
14	0 (0–0)	47.09 (36.16–58.03)	29.66 (20.03–39.30)	23.23 (21.93–24.53)	52.90 (41.97–63.84)	Muddy sand
15	0 (0–0)	74.24 (43.62–67.11)	16.25 (6.43–42.66)	9.50 (4.22–18.97)	25.75 (11.02–41.22)	Sandy gravelly mud
16	0 (0–0)	24.47 (0–48.98)	41.20 (31.42–50.97)	34.32 (19.62–49.02)	75.52 (51.05–100)	Muddy sand
17	0 (0–0)	19.15 (0–76.63)	40.69 (11.96–85.35)	52.79 (10.55–88.03)	80.84 (23.36–100)	Sandy mud
18	0 (0–0	47.58 (0–95.17)	28.38 (3.71–53.05)	24.02 (1.11–46.94)	52.41 (4.82–100)	Sandy mud
19	0 (0–0)	43.39 (0–60.93)	29.29 (19.77–37.79)	35.11 (19.45–62.20)	56.60 (39.06–100	Sandy mud
20	0 (0–0)	35.59 (0–54.66)	26.31 (14.42–34.81)	41.88 (21.46–85.57)	64.40 (45.33–100)	Sandy mud
21	0 (0–0)	44.17 (7.23–82.51)	26.30 (7.54–48.66)	20.41 (6.01–51.93)	55.82 (17.48–9276)	Sandy mud
22	0 (0–0)	47.19 (0–66.38)	26.43 (20.29–29.48)	29.10 (9.58–79.70)	52.80 (33.61–100)	Sandy mud
23	0 (0–0)	34.74 (14.18–53.91)	33.92 (8.21–49.77)	44.64 (14.09–77.60)	65.25 (46.08–85.81)	Sandy mud
24	0 (0–0)	27.71 (9.63–45.80)	18.81 (14.82–22.79)	53.46 (39.37–67.56)	72.28 (54.19–90.36)	Sandy mud
25	0 (0–0)	32.85 (0–70.70)	25.34 (17.05–34.34)	41.80 (12.24–65.65)	67.14 (29.29–100)	Sandy mud
26	0 (0–0)	7.57 (0–22.71)	21.13 (9.66–27.35)	71.29 (50.89–90.33)	92.42 (77.28–100)	Sandy mud
27	0 (0–0)	63.22 (42.08–78.51)	21.41 (10.54–27.38)	15.36 (7.81–39.89)	36.77 (16.22–56.22)	Sandy mud

***** Samples contain mud fraction less than 5%.

Table 3 Organic Matter contents, pH and EC values of Lake Nasser sediment during 2013.

Site	pH		EC		OM	
	Mean ± SD	range	Mean ± SD	range	Mean ± SD	Range
1	6.72 ± 0.239	6.38–6.92	698 ± 84.34	628–816	3.77 ± 2.14	3.08–5.11
2	6.70 ± 0.238	6.37–6.90	1436 ± 173.51	1292–1680	12.60 ± 8.23	2.52–22.7
3	6.44 ± 0.229	6.12–6.63	367 ± 44.34	330–429	4.21 ± 3.52	1.51–9.24
4	6.74 ± 0.240	6.4–6.94	586 ± 70.81	527–685	3.78 ± 0.89	3.07–5.04
5	6.85 ± 0.244	6.51–7.06	1543 ± 186.44	1388–1805	7.07 ± 5.10	3.41–14.29
6	6.61 ± 0.235	6.28–6.81	323 ± 39.03	290–377	2.00 ± 1.43	0.84–4.02
7	6.76 ± 0.241	6.42–6.96	647 ± 78.18	582–757	1.67 ± 0.68	1.02–2.33
8	6.71 ± 0.239	6.37–6.91	918 ± 110.92	826–1074	9.59 ± 2.89	6.69–13.45
9	6.83 ± 0.243	6.49–7.03	512 ± 61.87	460–599	4.58 ± 2.68	1.34–7.9
10	6.73 ± 0.240	6.39–6.93	715 ± 86.39	643–837	5.55 ± 0.78	4.55–6.18
11	6.90 ± 0.246	6.56–7.11	1660 ± 200.58	1494–1942	7.19 ± 1.27	5.55–8.64
12	6.77 ± 0.241	6.43–6.97	716 ± 86.51	644–837	6.68 ± 0.80	5.55–7.28
13	6.90 ± 0.246	06.56–7.11	1272 ± 153.70	1144–1488	5.55 ± 0.77	5.07–6.32
14	7.01 ± 0.249	6.66–7.22	984 ± 118.90	885–1151	5.95 ± 0.47	5.38–6.52
15	6.96 ± 0.248	6.61–7.17	740 ± 89.41	666–865	5.55 ± 0.45	5.17–6.13
16	6.93 ± 0.247	6.58–7.14	971 ± 117.33	873–1136	5.88 ± 0.55	5.21–6.56
17	7.22 ± 0.257	6.86–7.44	920 ± 111.16	826–1076	5.99 ± 0.94	4.87–6.89
18	7.22 ± 0.257	6.86–7.44	320 ± 38.67	288–374	4.79 ± 1.58	2.86–6.72
19	7.20 ± 0.256	6.84–7.42	474 ± 57.27	426–554	5.2 ± 2.68	2.1–8.57
20	7.09 ± 0.252	6.74–7.30	794 ± 95.94	714–928	5.04 ± 2.01	3.43–7.9
21	6.95 ± 0.247	6.6–7.16	280 ± 33.83	252–327	3.88 ± 2.06	1.85–6.22
22	7.17 ± 0.255	6.81–7.39	574 ± 69.36	516–671	3.05 ± 0.74	2.14–3.87
23	7.01 ± 0.249	6.66–7.22	969 ± 117.08	872–1133	3.65 ± 1.95	1.51–6.22
24	7.30 ± 0.260	6.94–7.52	392 ± 47.37	352–459	4.87 ± 0.55	4.2–5.55
25	7.44 ± 0.265	7.07–7.66	456 ± 23.20	425–482	3.26 ± 1.20	1.68–4.59
26	7.45 ± 0.265	7.08–7.67	462 ± 23.76	440–495	4.64 ± 0.83	3.53–5.53
27	7.25 ± 0.258	6.89–7.47	692 ± 83.61	622–809	4.54 ± 0.81	3.42–5.44

part of the Egyptian sector of the reservoir). Also, the distribution of grain size is controlled by depth, where clay and silt sizes increased with depth while sand fraction decreased in the same trend. This is a reflection of decrease in the following current competency. Some samples however, deviate from this pattern, this may be due to the presence of the Nubian sand stone and/or sand sheets on the shores, and due to the geomorphic features of the reservoir which lead to increase of gravel distribution.

pH values fluctuated between the lowest value of 6.12 at the west of High Dam sector during spring and the highest one of 7.67 in the main channel of Abu Simbel sector. EC shows a width ranging from 252 to 1942 µs/cm at the west of Amada sector during spring and main channel of Wadi-Abyad during summer, respectively. Organic matter ranged between maximum value 22.69% at the main channel of High Dam sector during spring and minimum value 0.84% at the western bank of Dahmit sector. The organic matter in main channel was high at High Dam sector, but low at Abu-Simbel and Tushka sectors. It means that organic matter increased from south to north. This is related to the grain size distribution. The results of the present study agreed with those obtained by Iskaros and El Dardir (2010) and Latif et al. (1989).

Levels of heavy metals

Table 4 shows that iron reached its maximum content 27.19 mg/g at the main channel of Abu-Simbel sector during spring, while it reached its lowest 1.51 mg/g at the main channel of High Dam sector during winter. Manganese shows irregular distribution patterns in Lake Nasser sediment as it fluctuated between 14.38 and 893.63 µg/g at the east of Wadi–Abyad and the west of High Dam sector, respectively during spring. The levels of zinc are low in comparison to the levels of manganese, where zinc content varied between 1.2 and 140 µg/g at the east of El-Madiq during winter and main channel of Tushka sector during spring, respectively. The highest copper value of 43.15 µg/g was detected at the west of High Dam sector during winter, while the lowest value of 1.05 µg/g was recorded at the east of Wadi–Abyad during the same season. Chromium levels fluctuated between 10.57 and 66.39 µg/g at the east and the west of Dahmit sector during spring and summer, respectively. The lowest value of nickel (4.15 µg/g) was recorded at the main channel of the High Dam sector during autumn, while the highest one (56.37 µg/g) was observed at the main channel of Korosko during spring. Lead varied between 2.0 and 34.62 µg/g at the main channel of the High Dam and Wadi–Abyad during summer and spring, respectively. Cadmium exhibited the lowest level of the studied metals in Lake Nasser sediments; it was depleted completely at some sites, while it showed a maximum of 0.6 µg/g at the east of Korsko in winter.

ANOV and correlation analysis

pH and EC values showed a highly significant difference ($P < 0.01$) between the various sites probably because of the sediment types. On the other hand the organic matter showed

Table 4 Levels of studied heavy metals (mean ± SD) of Lake Nasser sediment during 2013.

Site	Fe Mean ± SD	range	Mn Mean ± SD	range	Zn Mean ± SD	range	Cu Mean ± SD	range
1	8.63 ± 1.10	7.55–10.09	266.32 ± 33.87	232.93–311.48	13.47 ± 1.71	11.78–15.76	3.79 ± 0.48	3.31–4.43
2	3.13 ± 0.93	2.02–4.07	87.73 ± 28.27	55.52–117.85	11.48 ± 3.88	6.2–15.05	2.25 ± 0.58	1.5–2.75
3	8.03 ± 4.84	2.53–12.69	390.37 ± 350.22	83.86–893.6	26.98 ± 16.56	8.00–42.75	33.21 ± 7.98	23.89–43.15
4	14.90 ± 4.91	8.94–20.48	350.04 ± 65.20	275.96–409.33	38.43 ± 6.53	33.15–47.65	18.00 ± 10.21	8.45–32.45
5	11.73 ± 1.70	9.68–13.67	366.22 ± 93.97	296.33–498.57	33.23 ± 5.86	27.43–41.3	29.31 ± 3.92	28.3–32.45
6	9.79 ± 3.67	4.24–12.19	182.48 ± 53.85	100.46–233.54	12.37 ± 3.43	7.5–15.55	6.60 ± 4.06	1.32–11.2
7	11.00 ± 1.92	9.29–13.07	495.22 ± 86.46	418.4–588.38	59.94 ± 10.47	50.64–71.22	28.87 ± 5.04	24.4–34.31
8	12.45 ± 3.92	8.25–17.5	560.36 ± 108.43	465.38–704.02	67.82 ± 47.36	32.55–136.9	32.67 ± 5.26	28.2–39.15
9	8.79 ± 2.52	5.81–11.65	204.97 ± 23.95	188.43–234.26	25.17 ± 9.25	18.7–38.85	13.61 ± 7.81	3.15–19.85
10	4.35 ± 1.30	3.07–6.14	58.16 ± 35.60	14.38–99.2	12.72 ± 7.79	3.15–21.70	1.43 ± 0.48	1.05–2.10
11	15.41 ± 3.27	12.53–20.11	384.09 ± 156.83	271.66–612.11	32.30 ± 5.45	25.45–37.1	34.41 ± 2.91	32.38–38.65
12	5.21 ± 2.42	2.51–8.11	156.81 ± 107.86	23.86–280.63	12.77 ± 9.06	1.6–46.55	9.22 ± 5.51	2.45–15.45
13	19.40 ± 5.42	12.82–24.28	300.98 ± 43.19	265.65–362.64	24.97 ± 18.85	1.2–46.55	29.99 ± 4.31	27.47–29.70
14	8.85 ± 4.81	2.89–14.49	163.86 ± 99.22	40.86–280.99	14.15 ± 4.37	8.8–19	16.24 ± 11.81	1.6–30.3
15	14.01 ± 1.95	11.94–16.29	325.07 ± 45.28	276.98–378.11	53.08 ± 7.39	45.23–61.74	33.74 ± 4.70	28.75–39.25
16	14.47 ± 2.60	11.87–17.44	226.36 ± 49.20	170.58–272.74	83.82 ± 41.91	30.9–129.4	22.75 ± 6.98	14.15–29.35
17	10.96 ± 5.26	3.21–14.91	331.70 ± 311.20	64.93–766.64	32.21 ± 24.95	8.7–67.45	20.58 ± 13.48	1.5–31.1
18	13.82 ± 3.79	9.14–17.92	259.80 ± 73.15	186.1–354.17	32.93 ± 11.91	18.4–47.55	24.18 ± 6.41	14.85–29.05
19	13.97 ± 3.55	11.59–19.25	232.51 ± 67.27	171.84–306.19	31.10 ± 7.90	24.7–41.7	24.34 ± 10.16	9.45–32.35
20	15.01 ± 5.23	7.43–19.31	273.59 ± 106.10	149.51–374.98	31.24 ± 8.88	21.5–42.05	24.10 ± 9.20	10.45–30.45
21	12.35 ± 1.64	10.69–14.61	188.39 ± 27.79	160.72–222.88	28.56 ± 5.43	22.8–32.55	17.22 ± 3.38	13.55–20.37
22	14.71 ± 4.47	10.74–19.69	242.26 ± 80.40	149.06–333.63	31.56 ± 8.05	23.55–39.95	22.11 ± 4.96	16.65–28.25
23	16.37 ± 2.87	12.18–18.27	276.93 ± 64.73	201.26–359.1	61.26 ± 52.70	31.25–140	30.24 ± 2.47	28.05–33.65
24	12.48 ± 3.07	8.86–15.04	184.48 ± 34.61	148.43–222.29	40.31 ± 8.56	30.7–46.4	17.73 ± 4.44	12.45–21.45
25	18.48 ± 5.60	11.6–23.74	225.05 ± 51.29	165.83–271.15	45.31 ± 6.42	39.99–54.59	28.50 ± 4.62	24.45–34.34
26	19.83 ± 6.42	11.79–27.19	570.45 ± 256.98	220–777.22	45.31 ± 2.70	42.64–47.95	31.99 ± 1.50	31.11–33.65
27	17.15 ± 4.17	12.13–21.55	243.92 ± 37.80	202.6–276.5	52.82 ± 10.84	40.05–63.7	31.06 ± 3.13	28.15–35.08

Site	Cr Mean ± SD	Range	Ni Mean ± SD	Range	Pb Mean ± SD	Range	Cd Mean ± SD	Range
1	31.65 ± 10.89	20.02–46.32	14.59 ± 7.65	7.63–25.24	13.94 ± 4.33	9.14–19.62	0.098 ± 0.013	0.86–0.115
2	20.31 ± 9.93	10.36–34.28	11.65 ± 5.45	4.15–7.18	5.29 ± 3.45	2.0–16.28	0.076 ± 0.023	0.049–1.00
3	39.99 ± 8.87	28.74–50.2	34.45 ± 7.77	24.61–43.6	8.78 ± 5.31	4.17–16.21	0.159 ± 0.057	0.1-.222
4	42.99 ± 19.64	38.12–66.39	37.41 ± 13.95	23.03–56.29	9.21 ± 3.94	5.36–14.63	0.161 ± 0.063	0.1–0.25
5	40.93 ± 14.36	25.73–60.32	29.73 ± 9.43	19.36–42.18	9.92 ± 6.21	4.59–18.62	0.202 ± 0.149	0.04–0.40
6	20.21 ± 10.47	10.57–34.97	14.83 ± 5.08	9.42–21.62	14.39 ± 7.54	7.53–24.9	0.186 ± 0.105	0.45–0.30
7	33.86 ± 11.06	21.81–48.62	33.11 ± 7.83	23.38–42.55	5.69 ± 2.98	2.98–9.84	0.233 ± 0.041	0.197–0.277
8	36.72 ± 8.23	26.32–46.23	36.80 ± 6.84	27.48–43.68	5.62 ± 2.95	2.94–9.73	0.152 ± 0.125	Nd-0.252
9	32.61 ± 13.56	19.15–51.34	24.11 ± 6.98	16.14–33.14	15.72 ± 8.49	6.28–36.14	0.250 ± 0.147	0.05–0.4
10	25.36 ± 10.33	15.02–39.62	8.69 ± 2.07	6.69–11.58	6.57 ± 5.64	2.55–14.62	0.121 ± 0.017	0.10–0.14
11	35.67 ± 7.94	25.62–44.79	28.89 ± 6.92	20.34–37.29	20.97 ± 9.69	13.47–34.62	0.105 ± 0.064	0.05-.167
12	31.46 ± 8.19	21.7–41.68	22.53 ± 6.35	15.19–30.69	8.43 ± 2.99	5.89–19.43	0.138 ± 0.069	0.05–0.175
13	33.62 ± 9.16	22.89–45.26	36.06 ± 7.89	25.94–45.19	7.43 ± 3.90	3.89–12.85	0.240 ± 0.097	0.1–0.32
14	17.05 ± 3.07	13.43–26.31	8.63 ± 4.53	4.52–14.94	14.72 ± 6.44	8.47–23.58	0.228 ± 0.103	0.1–0.33
15	27.66 ± 8.98	17.85–39.64	34.50 ± 6.72	25.48–41.62	11.65 ± 6.11	6.09–20.15	0.248 ± 0.034	0.22–0.29
16	31.80 ± 8.31	21.91–42.19	21.27 ± 5.83	14.46–28.69	10.31 ± 5.40	5.39–17.38	0.300 ± 0.212	0.1–0.6
17	42.00 ± 8.77	30.63–51.62	37.24 ± 14.20	22.06–56.37	9.04 ± 4.74	4.73–15.63	0.150 ± 0.168	0.05–0.4
18	25.59 ± 5.49	18.59–31.62	37.85 ± 11.48	24.99–52.86	5.79 ± 2.98	2.77–9.29	0.206 ± 0.117	0.05–0.35
19	26.67 ± 6.56	18.69–34.62	35.17 ± 9.28	24.15–46.86	9.64 ± 5.05	5.04–16.68	0.216 ± 0.143	0.121–0.429
20	21.72 ± 8.36	13.16–33.19	20.23 ± 7.75	12.32–30.76	12.92 ± 6.77	6.76–22.35	0.231 ± 0.091	0.127–0.345
21	31.19 ± 7.22	22.19–39.68	21.22 ± 11.12	11.1–36.71	14.39 ± 7.54	7.53–24.9	0.191 ± 0.087	0.11–0.191
22	47.43 ± 9.18	35.12–56.78	29.18 ± 12.36	17.05–46.15	15.11 ± 3.87	10.12–19.27	0.148 ± 0.148	Nd-0.3
23	30.16 ± 7.58	21.0–39.48	39.57 ± 12.05	28.98–55.82	13.10 ± 5.81	7.49–21.1	0.098 ± 0.061	0.04–0.15
24	24.37 ± 5.99	17.08–31.62	21.72 ± 6.16	14.63–29.64	5.56 ± 4.09	2.21–11.32	0.100 ± 0.141	0.1–0.3
25	19.98 ± 7.47	12.25–30.19	32.64 ± 4.87	25.83–36.9	13.19 ± 6.91	6.9–22.81	0.226 ± 0.144	0.05–0.4
26	30.72 ± 9.16	20.37–42.69	32.56 ± 7.12	24.33–41.11	18.36 ± 8.74	11.73–31.09	0.214 ± 0.173	0.1–0.45
27	29.51 ± 9.96	18.8–42.89	39.52 ± 9.85	27.55–51.67	8.77 ± 4.60	4.59–15.17	0.064 ± 0.044	0.05–0.1

a significant difference ($P < 0.05$) and highly significant difference ($P < 0.01$) between the different seasons and locations, respectively. The studied heavy metals showed a perspicuous spatial high significant difference ($P < 0.01$) which may be attributed to geogenic process and geochemical compositions of the sediments in the bottom basin, in addition to the

Table 5 Concentration of studied metals in Lake Nasser sediment, geochemical background and the toxicological reference values for river sediments (μg/g).

Metal	Present result	Geochemical background		US DOE[c]			US EPA[d]	C-EQG[e]	
		Shale standard[a]	Earth crust[b]	TEC	PEC	HNEC		ISQG	PEL
Fe	12418	46700	56300						
Mn	279.6	950	850						
Zn	35.38	95	70	159	1532	541	110	123	315
Cu	21.78	40	55	28	77.7	54.8	16	35.7	197
Cr	30.79	90	100	56	159	312	26	37.3	90
Ni	27.56	68	75	39.6	38.5	37.9	16	–	–
Pb	10.91	20	12.5	34.2	396	68.7	31	35	91.3
Cd	0.175	0.3	0.15	0.59	11.7	41.1	0.6	0.6	3.5

Note: TEC = Threshold effect concentration; PEC = Probable effect concentration; HNEC = High no effect concentration; ISQG = Interim sediment quality guideline; PEL = Probable effect level; US DOE: U.S. Department of Energy's US EPA: U.S. Environmental Protection Agency; EQG: Canadian Environmental Quality Guidelines.
[a] Turekian and Wedepohl (1961).
[b] Taylor (1964).
[c] Jones et al. (1997).
[d] US EPA (1999).
[e] Environment Canada (2002).

leaching and mobilization of the elements in the different sites within the lake. Atemporal high significant difference ($P < 0.01$) for Fe, Cr, Ni, Pb and was confirmed, with a relative increase before the flood period, which indicated the role of transported suspended and dissolved solids with water flood which may be settled to the bottom sediment in the stagnation period (see Table 5).

Pearson's correlation coefficients ($n = 108$) among the measured parameters indicate that, pH is positively correlated with Fe ($r = 0.338$, $P < 0.01$), Zn ($r = 0.202$, $P < 0.05$), Ni ($r = 0.330$, $P < 0.01$), Cd ($r = 0.263$, $P < 0.05$) and mud ($r = 0.342$, $P < 0.01$). There is also a positive significant correlation between organic carbon with Mn ($r = 0.202$, $P < 0.05$) and with Ni ($r = 0.279$, $P < 0.01$), as found to be in agreement with the results obtained by Khalil et al. (2007) on Lake Burullus sediment; who stated that, the distribution of heavy metals in sediment is associated with the organic matter accumulation.

Most of sand fractions are negatively correlated with the studied heavy metals like Fe ($r = -0.288$), Cr ($r = -0.341$), Ni ($r = -0.329$) and Pb ($r = -0.453$) at ($P < 0.01$). Clay and mud fractions positively correlated with Fe ($r = 0.376$ & 0.310), Cr ($r = 0.277$ & 0.331), Ni ($r = 0.409$ & 0.372) and Pb ($r = 0.416$ & 0.331) for clay and mud, respectively at $P < 0.01$.

The positive correlations ($n = 108$, $P < 0.01$) of Fe/Cu ($r = 0.602$), Fe/Mn ($r = 0.450$), Fe/Ni ($r = 0.443$), Fe/Zn ($r = 0.376$), Mn/Cu ($r = 0.5851$), Mn/Zn ($r = 0.328$), Mn/Cr ($r = 0.328$), Mn/Ni ($r = 0.419$), Zn/Cu ($r = 0.423$), Zn/Ni ($r = 0.4$), Cu/Ni ($r = 0.496$) Cr/Ni ($r = 0.658$) indicate either their common origin or their common sink in the lake sediments, in addition to the association of these metals with Fe and Mn oxides as reported by Hassouna (1996). These results agreed with many authors (Dossis and Warren, 1980; Bertin and Bourg, 1995; Abdel-Satar, 1998; Goher, 2002), who have reported that the deposition of copper and zinc enhanced by the association of metals with clay minerals or by the adsorption of both copper and zinc on hydrated iron and manganese oxides. They added that the order of adsorption of most mobile metal fraction is Fe/Mn oxides > organic matter > clay.

Cd was not correlated with most of the studied metals; that may be attributed to the fact that Cd is carbonate dependent which is in agreement with those reported by Abdel-Satar (1998), Goher (1998) and supported by Borg (1984), who cited that heavy metals in carbonate with low solubility as Cd and Pb are completely eliminated from the solution as result as $CaCO_3$ co-precipitation. According to Patterson et al., 1977, most of the cadmium has been precipitated as carbonate instead of hydroxide when the pH was below 8.5.

Long term studies on the lake Nasser sediment indicated that Fe content fluctuated between 23.6 and 25.9 mg/g in 1977. Previous studies showed that the highest level 51–131 mg/g was recorded in 1995, while the present results established the lowest values 2.02–27.19 mg/g (Table 6). Manganese content oscillated from one year to the other, in 1967 for example, the recorded levels were 623–1067 μg/g, but in 1977 the lowest range of 59–138 μg/g was observed and the highest levels of 485–1305 μg/g was recorded in 1988. Zn and Cu have the same vibrated distribution pattern from High Dam construction until now. Cd exhibited a very high content (4.5–8 μg/g) during 1995 than that of the Earth's crust and of our results.

Indeed, long term studies have demonstrated and revealed the fluctuation of heavy metal content in Lake Nasser sediments with time. This fluctuation is probably attributed to the sampling location and natural geochemistry of sediment and/or due to the used techniques of sampling and the method of determination.

Ecological risk assessment

Enrichment factor (EF)

Enrichment factor (EF) is one widely used approach to characterize the degree of anthropogenic pollution to establish enrichment ratios (Zakir et al., 2008).

Table 6 Long Term Change of the studied metals in Lake Nasser sediment.

Element	1976[a]	1977[b]	1988[c]	1995[d]	2000s[e]	2013[f]
Fe mg/g		23.6–25.9	40.2–78.1	51–131		2.02–27.19
n µg/g	623–1067	95–138	485–1305	274–986	137.3–1237	14.38–893.6
Zn µg/g	104–158	1.5–2.1	77–432	35.5–87		1.2–140
Cu µg/g	50–80.5	6.5–12	56–81	22.5–68.5	9.74–68.28	1.05–43.15
Cr µg/g					17.62–89.28	10.57–66.39
Ni µg/g						4.15–56.37
Pb µg/g					4.81–15.51	2.00–36.14
Cd µg/g		–		4.5–8		ND-0.6

[a] Lasheen (1987).
[b] Elewa (1980).
[c] Elewa et al. (1990).
[d] Moalla et al. (1998).
[e] Darwish (2013).
[f] the present study.

A component enrichment factor (EF) was initially developed to speculate on the origin of elements in the atmosphere, precipitation, or seawater (Duce et al., 1975), but it was progressively extended to the study of soils, lake sediments, peat, tailings, and other environmental materials (Qingjie and Jun, 2008; Reimann and de Caritat, 2005). The enrichment factor (EF) is a convenient measure of geochemical trends and is used for making comparisons among areas. To evaluate the magnitude of contamination in the environment, the enrichment factors (EF) were computed relatively to the abundance of species in source material and to that found in the Earth's crust (Sinex and Helz 1981).

$$EF = (C_M/C_{Xsample})/(C_M/C_{X\text{Earths crust}})$$

where, C_M is the content of metal studied and C_X is the content of immobile element, immobile elements may be Al (Chatterjee et al., 2007), Fe and Ti (Zhang et al., 2007), Mn (Liu et al., 2005) or Li, Sc, Zr (Blaser et al., 2000). Iron was chosen as an immobile element because of natural sources (1.5% vastly dominate its input (Tippie, 1984). Many authors used iron to normalize heavy metal contaminants (Schiff and Weisberg, 1999; Baptista Neto et al., 2000; Mucha et al., 2003). In the present study, iron has also been used as a conservative tracer to differentiate natural from anthropogenic components. Several authors prefer to express the metal contamination with respect to average shale to quantify the extent and degree of metal pollution (Muller, 1969; Forstner and Muller, 1973). In this study, the background concentrations (the reference Earth's crust of Fe, Mn, Zn, Cu, Cr, Ni, Pb and Cd were taken from Turekian and Wedepohl (1961). The average abundance of Fe, Mn, Zn, Cu and Cd is 46700, 950, 95, 40, 90, 68, 20 and 0.3 µg/g, respectively.

Fig. 2 represents the EF values of measured trace metals in Lake Nasser sediments. Five contamination categories are generally recognized on the basis of the enrichment factor (Table 1), Sutherland (2000). From another point of view, EF value of an element is greater than unity; this indicates that the metal is more abundant in the sample relative to that found in the Earth's crust. Although EF values less than 5 may not be considered significant, they are indicative of metal accumulation, because such small enrichments may arise from differences in the composition of local sample material with respect to the reference Earth's crust ratio values used in the
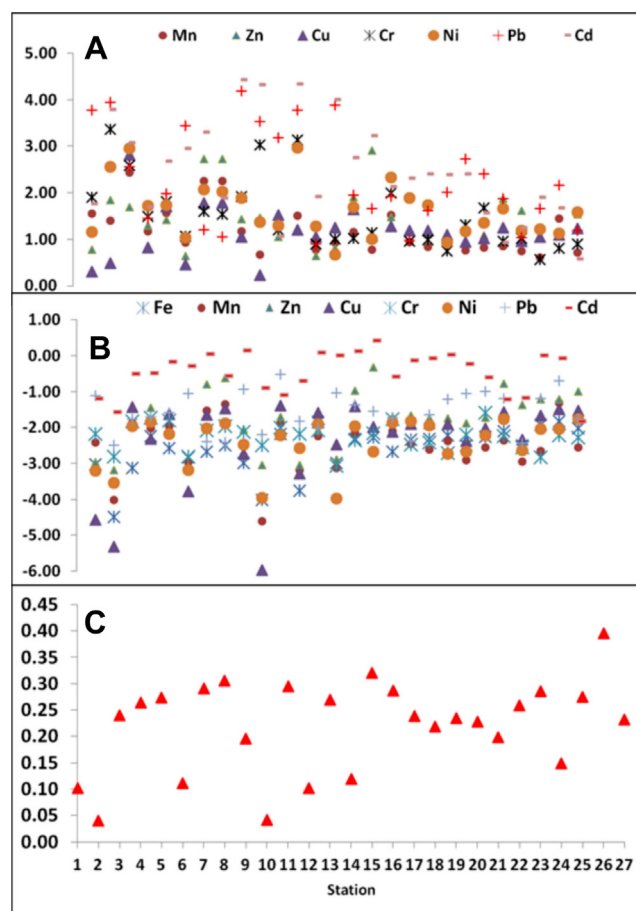
Figure 2 (A) Enrichment Factor (EF), (B) Index of geo-accumulation (I_{geo}) and (C) Pollution Load Index (PLI) values of measured trace metals in Lake Nasser sediments.

EF calculations, If the EF values are greater than 5, samples are considered contaminated (Atgin et al., 2000).

According to the above suppositions, Lake Nasser sediment is not contaminated with the studied metal (EF < 5), but it shows mild enrichment (EF > 1). The mean values of EF in the lake sediment were 1.18, 1.44, 1.17, 1.5, 1.62, 2.3 and

2.47 for Mn, Zn, Cu, Cr, Ni, Pb and Cd, respectively, which signify the anthropogenic source of Cr, Pb and Cd, this conclusion is in agreement with Zhang and Liu (2002) who stated that EF values between 0.5 and 1.5 indicate the metal is entirely from crustal materials or natural processes, whereas EF values greater than 1.5 suggest that the sources are more likely to be anthropogenic.

It is presumed that high EF values indicate an anthropogenic source of trace metals. The bioavailability and toxicity of any trace metals in sediments depend upon the chemical form and concentration of the metals (Kwon et al., 2001). It can be inferred that trace metals in sediment samples with the highest EF values; along with higher labile fractions in sediments, are potential sources for mobility and bioavailability in the aquatic ecosystems (Mohiuddin et al., 2010).

Index of geo-accumulation (I_{geo})

The geo-accumulation index I_{geo} values were calculated for the studied metals as introduced by Muller (1981) as follows:

$$I_{geo} = \log_2(cn/1.5 * bn)$$

where (cn) is the measured concentration of examined element (n) in the sediment sample and (bn) is the geochemical background for the element (n) which is either directly measured in pre-civilization (pre-industrial) reference sediments of the area or taken from the literature (average shale value described by Turekian and Wedepohl (1961). The factor 1.5 is introduced to include possible variation of the background

values that are due to lithogenic variations (Chakravarty and Patgiri, 2009), as well as very small anthropogenic influences (Qingjie and Jun, 2008). Muller (1981) proposed seven grades or classes of the geo-accumulation index. Different geo-accumulation index classes along with the associated sediment quality are given in (Table 1); the I_{geo} class 0 indicates the absence of contamination while the I_{geo} class 6 represents the upper limit of the contamination. The highest class 6 (very strong contamination reflects) 100-fold enrichment of the metals relative to their background values (Harikumar and Jisha, 2010). On the other hand, Karbassi et al. (2008) mentioned that I_{geo} and EF failed to various degrees to designate the intensity of pollution.

The calculated index of geo-accumulation I_{geo} of the investigated trace metals in the sediments of the Lake Nasser and its corresponding contamination intensity are illustrated in Fig. 2. I_{geo} values for all studied trace metals exhibited a zero class indicating unpolluted sediment quality.

Contamination factor (CF)

The level of contamination of lake sediment or a sub-basin by given toxic substance (metals) suggested by Håkanson (1980) is often expressed in terms of a contamination factor and is calculated as follows.

Contamination Factor (CF = metal content in the sediment/background level of metal). The pollution grade of sediment according to CF values is given in Table 7. The CF values of all studied metals were less than 1 in all sites indicating the good quality of Lake Nasser sediment.

Table 7 Contamination factor of the studied trace metals of Lake Nasser sediment.

Site	Fe	Mn	Zn	Cu	Cr	Ni	Pb	Cd
1	0.181	0.280	0.142	0.095	0.333	0.215	0.697	0.328
2	0.066	0.092	0.121	0.056	0.214	0.171	0.265	0.254
3	0.169	0.411	0.284	0.830	0.421	0.507	0.439	0.528
4	0.313	0.368	0.404	0.450	0.452	0.550	0.461	0.538
5	0.246	0.385	0.350	0.733	0.431	0.437	0.496	0.672
6	0.206	0.192	0.130	0.165	0.213	0.218	0.720	0.619
7	0.231	0.521	0.631	0.722	0.356	0.487	0.284	0.778
8	0.261	0.590	0.714	0.817	0.386	0.541	0.281	0.505
9	0.185	0.216	0.265	0.340	0.343	0.355	0.786	0.833
10	0.091	0.061	0.134	0.036	0.267	0.128	0.328	0.403
11	0.324	0.404	0.340	0.860	0.375	0.425	1.048	0.350
12	0.104	0.165	0.134	0.230	0.331	0.331	0.421	0.460
13	0.408	0.317	0.263	0.750	0.354	0.530	0.371	0.800
14	0.186	0.172	0.149	0.406	0.179	0.127	0.736	0.758
15	0.294	0.342	0.559	0.844	0.291	0.507	0.582	0.825
16	0.304	0.238	0.882	0.569	0.335	0.313	0.515	1.000
17	0.230	0.349	0.339	0.514	0.442	0.548	0.452	0.500
18	0.290	0.273	0.347	0.604	0.269	0.557	0.289	0.686
19	0.294	0.245	0.327	0.608	0.281	0.517	0.482	0.718
20	0.315	0.288	0.329	0.603	0.229	0.297	0.646	0.769
21	0.259	0.198	0.301	0.430	0.328	0.312	0.720	0.637
22	0.309	0.255	0.332	0.553	0.499	0.429	0.756	0.494
23	0.344	0.292	0.645	0.756	0.317	0.582	0.655	0.325
24	0.262	0.194	0.424	0.443	0.256	0.319	0.278	0.333
25	0.388	0.237	0.477	0.712	0.210	0.480	0.659	0.755
26	0.417	0.600	0.477	0.800	0.323	0.479	0.918	0.713
27	0.360	0.257	0.556	0.776	0.311	0.581	0.438	0.213
Mean	0.261	0.294	0.372	0.545	0.324	0.405	0.545	0.585

Pollution load index (PLI)

The pollution load index – PLI, proposed by Tomlinson et al. (1980) – has been used in the present study to measure PLI in sediments of Lake Nasser. The PLI for a single site is the *n*th root of the product of *n* contamination factors (*CF* values).

PLI for a site $= nth\sqrt{CF_1 * CF_2 * \ldots CF_{nt}}$
where, *CF* = contamination factor and *n* = number of metals
PLI for a zone $= nth\sqrt{site_1 * site_2 * \ldots site_n}$
where *n* equals the number of sites.

The pollution load index as presented in Fig. 2, provides simple comparative means for assessing a site or area quality (0.0 indicates perfection, 1.0 indicates only baseline levels of pollutants present and >1.0 indicates progressive deterioration of the site, Tomlinson et al., 1980; Cabrera et al., 1999). PLI values of sediments in the different sites of Lake Nasser ranged from 0.040 to 0.395 with average of 0.221. The PLI of the zone or the whole investigated area of the lake however, was 0.196 which confirmed that the lake sediments are not polluted. Our results of the ecological risk assessment are in compatible to some extent with that obtained by Darwish (2013) in the northern part of Lake Nasser, but they are incompatible with his results for the southern part.

The PLI can provide some understanding to the public of the area about the quality of a component of their environment. It also indicates the trend spatially and temporarily. In addition, it also provides valuable information and advice to the policy and decision makers on the pollution level of the area (Mohiuddin et al., 2010; Harikumar and Jisha, 2010).

The results of Cf, I_{geo} and PLI indicate the low down human activity in and around Egyptian Lake Nasser.

Conclusion and recommendation

The results of this study supply valuable information about some heavy metal contents of sediment from different sites along Lake Nasser, and we can conclude and recommended that

- The distribution pattern of the heavy metals under investigation in Lake Nasser sediments reflected a perspicuous spatial high significant difference ($P < 0.01$) for the all measured metals, while Fe, Cr, Ni, Pb and Cd exhibited a temporal high significant difference ($P < 0.01$), before and after the flood period.
- Although, *EF* Values showed mild enrichment ($EF > 1.5$) in some sites, but the low values of *CF*, I_{geo} and PLI indicated the low human activity in and around Egyptian Lake Nasser.
- According to the geo-accumulation and Pollution indexes for the studied metals, Lake Nasser has uncontaminated sediment. Sediment of Lake Nasser may be represented as a reference for pre-industrial background of River Nile Sediments downstream Aswan High Dam.
- Systematic investigation is recommended to monitor metal loading and change in the lake sediment quality.
- Achievement of mathematical models to predict the effect of the expected low water level of the lake (due to the construction of El Nahda Dam on the Blue Nile in Ethiopia) on the ecological status of the Lake and also on its water and sediments' quality, its content of heavy metals and the metals' mobility between the water and sediment, in addition to the lake biodiversity.

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