Assessment of Contamination in Sediments of Lake Nubia in Sudan

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Abstract

The heavy metals deposited in the sediment are probably due to anthropogenic and natural sources. It can be said that the environmental or human impact involving these metals is occurring in the aquatic environment and can cause hazard to sediments dwelling organisms as well as the populace in the area through food chain. On the other hand climate changes are projected to reduce raw water quality as increased sediment, nutrient, and pollutant loadings from heavy rainfall. Greater runoff results in greater loads of salts, faecal coliforms, pathogens and heavy metals. The environmental pollution of heavy metals in the sediment of the north part of Lake Nubia, Sudan was assessed. Heavy metals data from 12 locations were obtained from literature review as sediment samples were collected and analyzed in 2009. The degree of contamination in the sediments of Lake Nubia, for the metals Cu, Pb, Zn, Fe, and Mn has been evaluated using Geo-accumulation index (Igeo) and Pollution Load index (PLI). Seven and two contamination classes and terminologies suggested for Igeo and PLI respectively were used in this paper. Igeo results for sediments in the studied area ranged from (-34.51) to (-2.4). PLI for all locations are less than 1. Results of Igeo and PLI for sediment in different studied locations indicated that the sediment quality is unpolluted for whole locations in the studying area. The results recommended that these cleaned sediments may be very useful for agriculture using in residential regions around the Lake Nasser/Nubia. On the other hand the characteristics for all Lake Nasser/Nubia sediment are necessary to evaluate its potential using for agricultural.

Keywords: Heavy Metals, Sediment , Igeo, PLI, Lake Nubia.

1. INTRODUCTION

The aquatic environment quality is projected to reduce due to climate change. The sources of the risks on water quality are increased temperature, nutrient and pollutant loadings due to heavy rainfall, and increases in sediment. Greater runoff results in greater loads of salts, faecal coliforms, pathogens and heavy metals (Pednekar*et al*, 2005). Increased in temperature appears that adsorptive capacity for heavy metals in sediment increases when the temperature rises (WMO, 2003).

Water, sediment and biota can use as an indicator to determine the level of heavy metal pollution in aquatic environment. Sediments are important sinks for various pollutions like organic and inorganic (heavy metal) and also play a significant role in the assessment of ecological risk (Balls *et al*, 1997). Heavy metals are of high ecological significance since they are not removed from water through self purification or biodegradable, they can either be adsorbed on sediment particles or accumulated in aquatic organisms (Loska and Wiechula, 2003). The concentrations of heavy metals in sediments are varied according to the rate of particle sedimentation, the rate of heavy metals deposition, the particle size and the presence or absence of organic matter in the sediments (Saloman*et al*, 1987). Gessey*et al*, 1984 stated that heavy metals react readily with suspended particulate matters and through sedimentation processes, accumulate in bottom deposits. Sediment not only acts as the carrier of contaminants, but also as the potential secondary sources of contaminants in the aquatic system (Calmano*et al*, 1990). Elewa*et al*, (1990) reported that the bottom sediment acts as accumulator for heavy metals and the rate of accumulation depends mainly on different environmental parameters. This means that any change in environmental conditions in the system may render the remobilization of metals from the sediments (Calmano*et al*, 1993). So the accumulation of metal contaminants in sediments can pose serious environmental problems to the surrounding areas. Trace metal contamination in sediment could affect the water quality and the bio-assimilation and bio-accumulation of metals in aquatic organisms, resulting in potential long-term implications on human health and ecosystem. Essential metals such as Cu, Zn and Fe have normal physiological regulatory functions (Hogstrand and Haux,2001), but may bio-accumulate and reach toxic levels. Non-essential metals are usually potent toxins and their bio-accumulation in

tissues lead to intoxication, decreased fertility, tissue damage and dysfunction of a variety of organs (Damek-Proprawa and Sawicka-Kapusta,2003).
Heavy metals have received the attention of researchers all over the world, mainly due to their harmful effects on plants, especially those on vegetative and generative parts of the plants. Some metals, e.g. Mn, Cu, Zn, Mo and Ni, are essential or beneficial micronutrients for microorganisms, plants, and animals, but at high concentrations all these metals have strong toxic effects and pose an environmental threat (Tahar and Keltoum, 2011).

The Nile receives its water from two main watershed areas, the Equatorial East African Plateau which feeds the White Nile, and the Ethiopian Highlands which feed the Sobat, Atbara and the Blue Nile. The contribution of the Blue Nile is most important since 86% of the main Nile's annual discharge is derived from the Ethiopian Highlands, while only 14% is contributed by the Equatorial Lakes (Mancy and Hafez, 1979). Furthermore, the fluvium carried by the main Nile originates exclusively in the Ethiopian Highlands and is carried by the Blue Nile. The annual mud load of the main Nile is consisting of a mixture of sand, silt, clay and organic matter. When the reservoir was filling, the distribution of siltation covered wider areas depending on the size of the flood. Particularly heavy siltation occurs in the area 360 km south of Aswan High Dam, which is between Amka and El-Doeishat.

Since the construction of the Aswan High Dam in 1964, Egypt has carried out extensive measurements for deposited sediments in its reservoir, which it is annually about 130 million cubic meters of sediments with 85% in Sudan and 15% in Egypt. The results point to continuous accumulation of sediments totalizing more than 6 billion cubic meter without much use (Abulnaga and Abdel-Fadil, 2008).

Lake Nasser/Nubia water subjected to many studies covering the quantity and quality of stored water. There is a growing concern of the need of sediment quantity and quality management in the Lake. Therefore, inspections monitoring, and management should be considered annually to assess the decision maker in management the all aquatic environment of Lake.

The occurrences of elevated concentrations of trace metals in sediments can be a good indicator of man induced pollution rather than natural enrichment of the sediment by geological weathering (Wakida*et al*, 2008). Index is a powerful tool for processing, analyzing, and conveying raw environmental information to decision makers, managers, technicians, and the public. There are two types of sediment indices, single and integrated indices which were tools used to classify the sediment pollution rank. Single indices are indicators used to calculate only one metal contamination, while integrated indices are considered as indicators used to calculate more than one metal contamination. Each kind of integrated index might be composed by one of the single indices separately. The EGAPI Software that was developed by Qingjie *et al*, (2008) was in a single document interface and used to calculate the four single and eight integrated indices by heavy metals to assess the quality of sediment ecological geochemistry. The most common single index one is the geo-accumulation index (I-geo). On the other hand the pollution load index (PLI) for single index contamination factor (CF) also used in this paper as integrated index. These indices used in this paper were useful in the future studies and researches as a tool to indicate potential options for utilizing the sediments once it becomes necessary to remove them from the Lake Nasser/Nubia reservoir.

2. MATERIAL AND METHODS

Heavy metals are natural constituents of the Earth’s crust. Human activities have drastically altered the balance and biochemical and geochemical cycles of some heavy metals. The majority of trace elements originate from igneous rock. These concentrations can be used as background concentrations or concentrations that are unaffected by anthropogenic sources. Many authors prefer to express the metal contamination with respect to average shale to quantify the extent and degree of metal pollution (Muller, 1969).

The sediment pollution level by a given heavy metals was evaluated through pollution index with both single and integrated indices. Geo-accumulation index (I_{geo}) is a single one and pollution load index (PLI) for a single index of contamination factor (CF) is an integrated one used in this paper.

Geo- accumulation index (I_{geo})

Geo-accumulation was determined by the equation of Muller (1969) in order to determine and define metal contamination in sediments by comparing current concentrations with background levels by the following equation:

$$\mathrm{Igeo} = \log_2 \frac{\mathrm{Cn}}{1.5*\mathrm{Bn}} \qquad (1)$$

Where, Cn is the measured concentration of element "n" in the sediment and Bn is the geochemical background for the element "n" which is taken from the literature (world average shale value described by Turekian and Wedepohl, 1961). The factor 1.5 allows for the analysis of possible variations in background values for a given metal in the environment as well as very small anthropogenic influences (Loska*et al*, 2004), this means it is the background matrix correction in factor due to lithogenic variations. Muller (1969) proposed seven grades or classes of the geo accumulation index as the following:-

1. Class 0 (uncontaminated): Igeo< 0;
2. Class 1 (uncontaminated to moderately contaminated): 0 <Igeo< 1;
3. Class 2 (moderately contaminated): 1 <Igeo< 2;
4. Class 3 (moderately to strongly contaminated): 2 <Igeo< 3;
5. Class 4 (strongly contaminated): 3 <Igeo< 4;
6. Class 5 (strongly to extremely contaminated): 4 <Igeo< 5;
7. Class 6 (extremely contaminated): 5 <Igeo.

Pollution load index (PLI)

The pollution load index (PLI) proposed byTomlinson *et al* (1980) has been used to calculate PLI in sediments of north lake Nubia according to the following equation:

$$\mathrm{PLI} = \left(\prod_{i=1}^{m} P_i\right)^{1/m} \qquad (2)$$

Where "m" is the number of metals studied and P_i is the single pollution index of metal "i". P_i is the single index as contamination factor (CF)and calculated as follows:

$$\mathrm{CF} = \frac{\mathrm{Cn}}{\mathrm{Bn}} \qquad (3)$$

Where Cn is element concentration and Bn is the geochemical background for the element "n" which is taken from the literature (world average shale value described by Turekian and Wedepohl, 1961)
The world average shale concentration of Cu (45 µg/g), Fe (47200 µg/g), Mn (900 µg/g), Pb (20 µg/g), and Zn (95 µg/g) reported for shale were considered as the background value.

The data set used for Igeo and PLI calculated along north Lake Nubia obtained from literature review after Abou El Ella and El Samman (2010) as sediment samples collected and analyzed in winter (December 2009), along the north part of Lake Nubia, Sudan. Heavy metals data for lead, zinc, iron, copper, and manganese in 12 locations figure (1), along the north Lake Nubia was used in this study.

These heavy metals were used for calculation of Igeo and PLI by using of Pollution Index calculation for Ecological Geochemistry Assessment (EGAPI) software. The EGAPI software is a single document interface figure (2). The EGAPI software interface includes three parts; sources data, calculation methods, and result data. Source data in EGAPI software are the contents of heavy metals with specified format in a notepad text file. As well as result data are the calculated Igeo and PLI results saved in a notepad text file also.

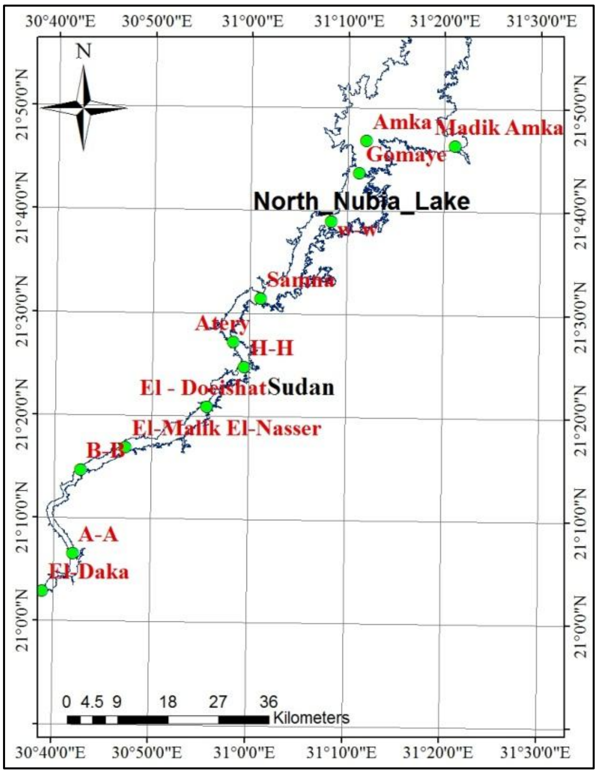

Figure 1: Layout of north Lake Nubia and Studying Locations

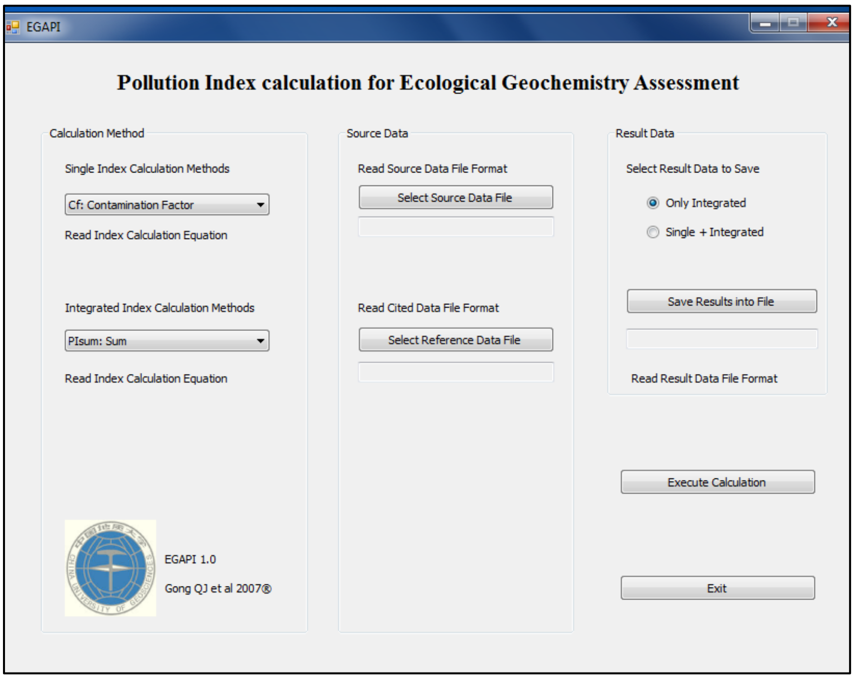

Figure 2: EGAPI Software Interface

The heavy metal concentrations also compared with those metals available in Canadian Soil Quality Guidelines (CCME, 2007) to study the availability of sediment quality for its using in agriculture and Canadian Sediment Quality Guidelines (CCME, 1995) to evaluate the sediment quality for aquatic organisms.

After Igeo and PLI were calculated at different locations on north Lake Nubia, GIS-Arcmap software was used to plot three dimensional surfaces that approximate the actual areas for selected heavy metals variation, degree of Igeo and PLI levels for the same heavy metals across the study area by geo-statistical methods. Spatial interpolation was done by assigning heavy metals concentrations, Igeo and PLI values at different sites to their respective GPS coordinates.

Though, there are many Geo-statistical methods for interpolation techniques available but Kriging is most suitable and having many advantages over others and used for spatial interpolation analysis in this paper. In Kriging method, there several Models (Circular, Spherical, Exponential, and Gaussian…..) were tested for each heavy metals concentrations and their Igeo and PLI for the selection of the best one. Predictive performances of the fitted model were checked on the basis of cross validation tests. The values of mean square error (MSE), root mean square error (RMSE), average standard error (ASE) and root mean square standardized error (RMSSE) were estimated to ascertain the performance of the developed models. A good and satisfactory model are obtained as, the MSE near to zero, the RMSE is close to the ASE, and the RMSSE near to one.

3. RESULTS AND DISCUSSION

The results of this paper discussed the variation of heavy metals values in the north of Lake Nubia sediments, Sudan with respect to Canadian Soil Quality Guidelines (CCME, 2007) and Canadian Sediment Quality Guidelines (CCME, 1995.The level of heavy metals contamination at stations along studying area through geochemical calculations by using geo-accumulation index and pollution load index was also asses. Finally the results of geo-accumulation index, pollution load index and heavy metal concentrations at each location were plotted in Lake Nubia map and interpolation for the area of study was carried out using geostatistical techniques-GIS.

3.1 Heavy Metal Concentrations

The results of the heavy metals concentrations have been compared with two guidelines, Canadian Soil Quality Guidelines and Canadian Sediment Quality Guidelines. There are two reference values are established for Canadian Sediment Quality Guidelines. The first one is Probable Effective Level (PEL) that represents the concentration above which adverse effects are expected to occur frequently. The second is Threshold Effective Level (TEL) that represents the concentration below which adverse effects are expected to occur only rarely. The range between TEL and PEL is the possible effect range within which adverse effect occasionally occur.

The average range of copper concentration is between 3.15 µg/g and 12.83 µg/g. Copper concentration is below the level (63 µg/g) according to soil quality at all sites. The mean Zinc concentration ranged from 0.26 µg/g to 8.25 µg/g, and is far below the maximum acceptable limit for agricultural land use 200 µg/g. The mean lead values range from 0.05 µg/g to 0.9 µg/g. For agricultural land use, the maximum acceptable concentration of lead is 70 µg/g. Lead concentration in the sediment is therefore within acceptable limits for agricultural use. No pollution of the sediment according to Canadian Soil Quality Guidelines was observed at the studying locations as in table (1). So the using of the sediment without specific risk assessment for agricultural use is possible.

According to the Canadian sediment quality guideline comparison ,the levels for the available guideline parameters (Zn, Cu, and Pb) are below TEL values as in table (1).This implies that the occasional toxic effects are not expected from these metals, so no risk observed from accumulated heavy metals in sediment on aquatic organisms.

Table 1: Minimum and Maximum Heavy Metals Values and Canadian Guidelines

Heavy Metals	Minimum	Maximum	Canadian Guidelines		
			Sediment		Soil
			PEL	TEL	
Cu	3.15	12.83	197	35.7	63
Zn	0.26	8.25	315	123	200
Fe	22.8	92.8	----	----	----
Mn	17.5	93.2	----	----	----
Pb	0.05	0.9	91.3	35	70

3.2 Pollution Index

There are two types for pollution index, single and integrated indices. The single index used in this paper is geo- accumulation. The integrated index one is pollution load index for single contamination factor index.

3.2.1 Geo-accumulation Index (Igeo)

With the development of ecological and exploration geochemistry survey, a great deal of data related to heavy metal concentration in aquatic sediments have been measured which can be used to assess the quality of ecological and geochemical environments. Many calculation methods have been presented to assess the environmental quality; one of such important methods is the geo-accumulation index.

Geo-accumulation index is another assessment method was applied in this paper to assess the environmental status of the heavy metal pollution of the sediment in north of Lake Nubia. The geo-accumulation index is a quantitative measure of the degree of pollution in the aquatic sediments (Singh *et al*, 2005).

The geo-accumulation index (Igeo) for five heavy metals associated with the sediments in north of Lake Nubia, were calculated for 12 sites by using EGAPI software. Source data in EGAPI software were classified as source data and reference data. Source data are the contents of heavy metals with the specified format in a notepad text file (figure, 3). Reference data are background level for heavy metals for calculating Igeo in a notepad text file (figure, 4).

Heavy Metal Conc. - Notepad

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Locations	Cu	Zn	Fe	Mn	Pb
El-Daka	12.83	6.25	92.8	71.9	0.63
A-A	3.15	2.5	58.8	49.7	0.05
B-B	7.2	5	77	30.3	0.73
El-MaliklEl-Nasser	10.08	1.17	48	83.3	0.53
El-Doeishat	3.75	6	91.7	60.9	0.23
H-H	5.18	0.5	71.3	64.1	0.63
Atery	6.75	3	36.5	81.3	0.43
Samna	5.85	8.25	88.3	17.5	0.53
W-W	4.95	0.5	22.8	93.2	0.45
Gomaye	4.43	0.26	43.9	24.7	0.9
MadikAmka	4.05	2.75	65.8	78.5	0.63
Amka	5.18	2.5	87.5	86.5	0.15

Figure 3: Heavy Metals (µg/g) in north Lake Nubia (Source Data File for EGAPI)

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5	2
Cu	45
Zn	95
Fe	47200
Mn	900
Pb	20

Figure 4: Heavy Metals Background Levels (µg/g) (Reference Data File for EGAPI)

The Igeo values for the study area sediments vary from metal to metal and site to site (across metals and sites). Figure (5) presents the variation of the geo-accumulation index results for the quantification of heavy metal accumulation at studying locations. According to the classification of Igeo suggested by Müller (1969) and the output results from EGAPI software for Igeo, the sediment in Lake Nubia are in grade "0" which suggesting that the sediments in the study area are in background value with respect to this metal. This suggests that the sediments of north Lake Nubia are having background concentrations for five studying elements are practically unchanged by anthropogenic influences. This mean that, the heavy metal concentrations within the study area are pointed to the fact that naturally and primarily derived from geochemical background. So the sediments are unpolluted with respect five heavy metal studies.

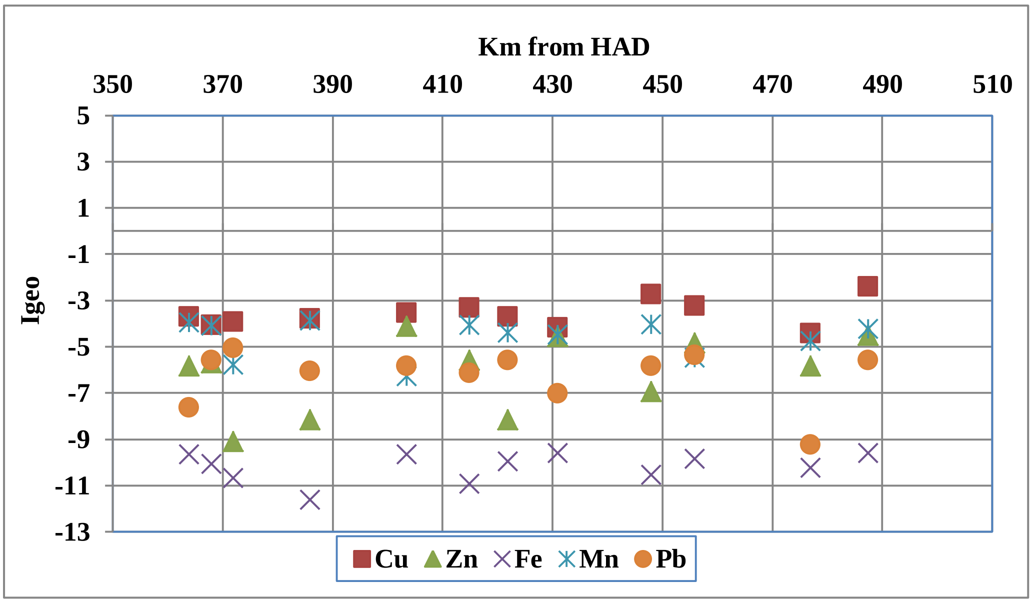

Figure 5: Igeo Variations along North Lake Nubia

3.2.2 Pollution Load Index (PLI)

The pollution load index which is based on single index as contamination factor (CF) for each metal was presented in figure (6). PLI provides a simple, comparative means in order to compare the pollution status at different locations. The PLI value more than"1" is polluted, whereas less than "1" indicates no pollution (Harikumar *et al*, 2009).PLI values of sediments of the studied locations ranged from 0.013 to 0.039.The values of Pollution Load Index were found to be low than "1" in all the studied locations.

PLI_CF - Notepad

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Locations	CF_Cu	CF_Zn	CF_Fe	CF_Mn	CF_Pb	PLI_CF
El-Daka	0.285	0.066	0.002	0.080	0.032	0.039
A-A	0.070	0.026	0.001	0.055	0.003	0.013
B-B	0.160	0.053	0.002	0.034	0.037	0.028
El-MaliklEl-Nasser	0.224	0.012	0.001	0.093	0.027	0.023
El-Doeishat	0.083	0.063	0.002	0.068	0.012	0.024
H-H	0.115	0.005	0.002	0.071	0.032	0.018
Atery	0.150	0.032	0.001	0.090	0.022	0.024
Samna	0.130	0.087	0.002	0.019	0.027	0.026
W-W	0.110	0.005	0.000	0.104	0.023	0.015
Gomaye	0.098	0.003	0.001	0.027	0.045	0.013
MadikAmka	0.090	0.029	0.001	0.087	0.032	0.025
Amka	0.115	0.026	0.002	0.096	0.008	0.021

Figure 6: EGAPI Output Results for PLI_CF along North Lake Nubia Locations

From the above three estimations this study concluded that the sediment quality at the locations in the study area of north Lake Nubia are unpolluted and heavy metal contamination in sediments was attributed to natural processes or logical mineralogy. This result are matched with Heikal (2008) and

Yousry (2011) who reported that most metals in Lake Nasser/ Nubia bed sediment have primarily moved to bind with organic and residual forms and the sediment is relatively unpolluted.

3.3 Spatial Variation for Heavy Metals Parameters, Igeo, and PLI

Spatial distribution of Cu, Mn, Fe, Pb, and Zn concentrations value and their Igeo and PLI_CF were carried out through GIS-Arc map through Geo statistical techniques. Ordinary Kriging was used to obtain the spatial distribution of heavy metals parameters, Igeo and PLI_CF over the area of study.

From geo-statistical model, Spherical model is the best-fitted one as its output for root mean square error (RMSE) and average standard error (ASE) (show small difference),mean square error (MSE) near to zero value, and root mean square standardized error (RMSSE) near to one value, as in table (2) for heavy metal concentrations, Igeo, and PLI. The variations according to GIS technique in the map of the studied area of north Lake Nubia illustrated in the figure (7).This figure represented the distributions maps for studied heavy metals; concentrations, Igeo, and PLI_CF.

Table 2: Validation Tests for Prediction Errors in Spherical Model

Parameters		RMSE	ASE	MSE	RMSSE
Pb	Metal conc.	0.281	0.2610	-0.009	1.071
	Igeo	1.338	1.2160	0.017	1.090
Zn	Metal conc.	2.843	3.3320	-0.042	0.854
	Igeo	1.683	1.7550	-0.025	0.964
Cu	Metal conc.	2.800	2.5530	-0.095	1.073
	Igeo	0.610	0.56280	-0.063	1.068
Mn	Metal conc.	28.120	28.2700	-0.050	0.999
	Igeo	0.871	0.8920	-0.048	0.981
Fe	Metal conc.	25.290	25.6400	-0.007	0.989
	Igeo	0.670	0.6820	-0.011	0.987
PLI_CF		0.010	0.0091	-0.077	1.099

The distribution maps in north Lake Nubia for studied heavy metals concentrations compared with the available heavy metals Canadian guidelines. These maps showed that the heavy metals concentrations within the permissible limit for Canadian sediment and soil standard in all study area of north Lake Nubia. As well as the distribution maps clearly reveals that the Igeo and PLI_CFat the area of study are unpolluted with respect to the measured heavy metals parameter Cu, Zn, Pb, Fe, and Mn.

4. CONCLUSION AND RECOMMENDATIONS

The comparison of trace metals concentration in north Lake Nubia sediments with TEL and PEL for Canadian Sediment Quality Guidelines values as well as Canadian Soil Quality Guidelines reveals that the concentration of studied heavy metals in the present sediments is in the permissible guidelines for aquatic organisms as well as for sediment uses in agricultural. In addition, Igeo are in grade “0” and PLI less than one that means that the quality of sediment according to corresponding heavy metals is unpolluted.

Finally, the results of this paper concluded that the accumulation of heavy metals in the bed sediments in north Lake Nubia did not represent environmental pollution risk and practically unchanged by anthropogenic influences can be observed according to the indices results according to data in 2009. It is recommended that the sediment in Lake Nasser/Nubia should be studied for identifying their quality in agriculture and other uses. More heavy metals parameters should be studied to illustrate in a more comprehensive view if their quality was affected or not on aggregated residential around the Lake.

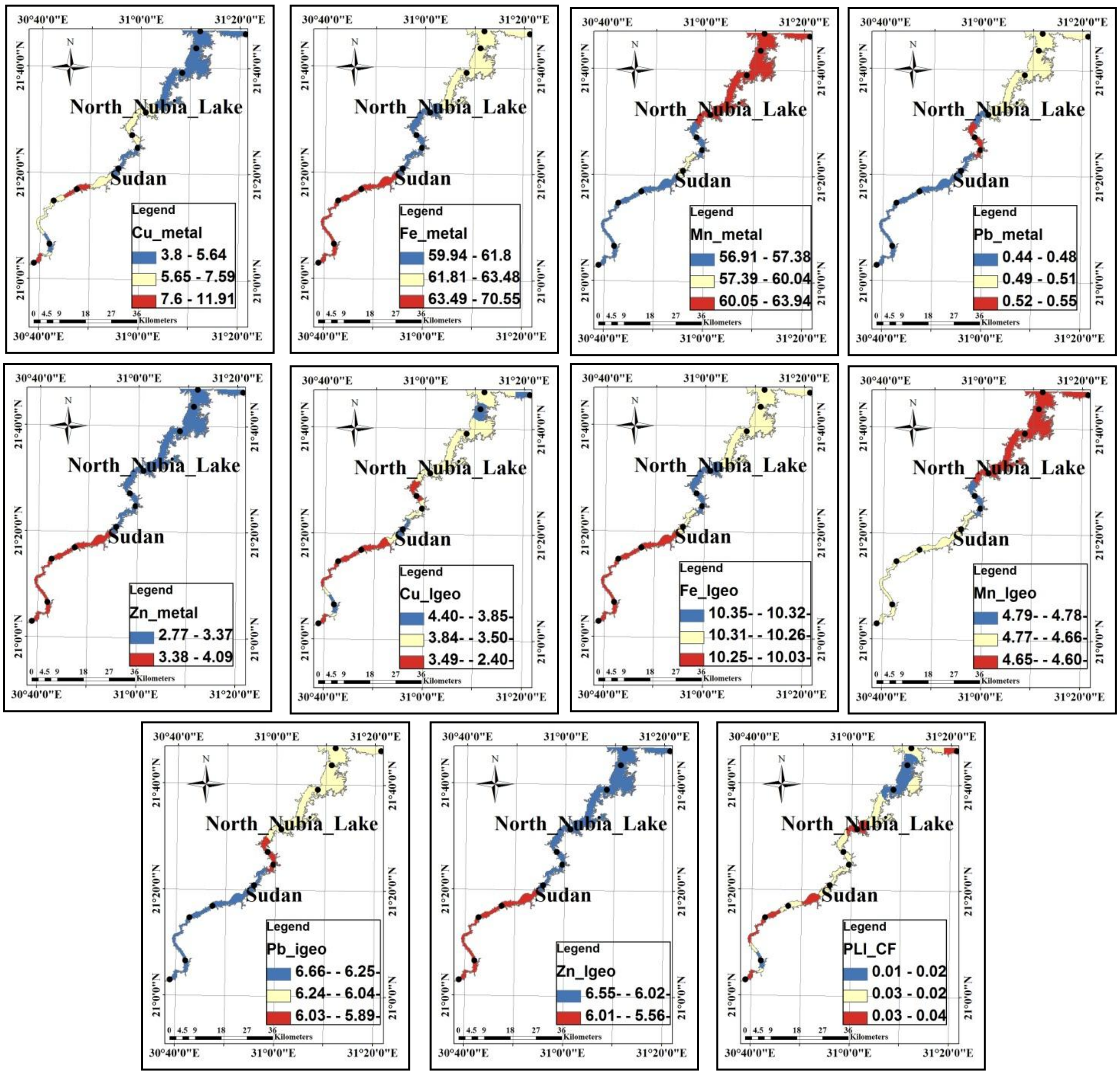

Figure 7: Metals, Igeos, and CF_PLI Levels Variations along North Lake Nubia

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