Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 25(1): 983 – 1015 (2021)
www.ejabf.journals.ekb.eg

Aluminum, Chromium and Manganese in Sediments of Bahr Shebeen Nilotic Canal, Egypt: Spatial and Temporal Distribution, Pollution Indices and Risk Assessment

Elsayed A. Khallaf[1*], Mohammad M.N. Authman[2] and Alaa A. Alne-na-ei[1]

[1]Zoology Department, Faculty of Science, Menoufia University, Shebeen Alkoom, Egypt

[2]Hydrobiology Department, National Research Centre, 33 EL Bohouth St. (Former EL Tahrir St.), Dokki, P.O. 12622, Giza, Egypt

***Corresponding author: ekhallaf@yahoo.com**

ARTICLE INFO

Article History:
Received: Jan. 3, 2021
Accepted: Feb. 26, 2021
Online: Feb. 28, 2021

Keywords:
Aluminum,
Chromium,
Manganese,
Sediments,
Nile Canal,
Egypt.

ABSTRACT

The distribution of aluminum (Al), chromium (Cr), and manganese (Mn) in Bahr Shebeen Nilotic Canal (BSC) sediments were studied during the period from September 2014 to December 2015, at different selected sites (S1, S2, and S3) over the BSC at Shebeen Alkoom City, Menoufia Province, Egypt. Spatially, the levels of Al and Mn at different sites are arranged as follows: Site S1>Site S3>Site S2, whereas Cr levels were found to be in the following arrangement: Site S1>Site S2>Site S3. Seasonally, Al concentrations levels followed the order of summer> winter> autumn>spring, whereas the Cr and Mn levels were arranged in the order of winter> autumn>spring>summer. The different pollution indices of sediment and sediment quality guidelines (SQGs) showed that the BSC has uncontaminated, to low/or moderately contaminated sediments. Such occurrence might be related to biologically harmful health influences to the sediment-dwelling biota. The humans' hazard index (HI) values for adults were greater than one; therefore, there were chances of having non-cancer risk for all studied metals on adult health through dermal contact exposure. However, Cr value is considered a carcinogenic risk, since its index (CRI) is more than the threshold level, designating that exposed adult humans are facing that risk. Finally, it is recommended that untreated wastes should be prohibited to reduce metal pollution.

INTRODUCTION

Heavy metals (HMs) were reported as dangerous contaminants for aquatic environments as a result of their persistency, bio-magnification, and bio-accumulation in the food chains, and toxicity effects on living organisms (Oyewumi *et al.*, 2017; Khallaf *et al.*, 2018a; Bing *et al.*, 2019; Xia *et al.*, 2020). The presence of domestic and industrial discharges, in addition to distributed agricultural inputs, could influence the aquatic environments, leading to the elevation of the potentially toxic element concentrations (Soliman *et al.*, 2018; Bibi *et al.*, 2020). The HMs pollution increasing has substantial adverse effects on invertebrates, fish, and human health (Yi *et al.*, 2011; Rodríguez Martín *et al.*, 2015; Proshad *et al.*, 2018). They were partitioned among various components of the aquatic environment (water, biota, suspended solids, and sediments) (Shakweer and Abbas, 2005). As soon as they were drained to water sources, they became adsorbed on the sediment particles and accumulated in higher levels (Loska and Wiechuła, 2003). It is evident that about 99% of the HMs in the aquatic ecosystems are transferred eventually to the bottom sediment (Peng *et al.*, 2009; Goher *et al.*, 2019).

Sediments; in the fluvial environments; can be contaminated by numerous types of harmful matters and HMs (Proshad *et al.*, 2019). Sediments had been known as a ready sink or storage of contaminants, including HMs, where they accumulate according to the pollution level (Muohi *et al.*, 2003; Abdel-Satar, 2005; Xia *et al.*, 2020). HMs concentrations in sediments are influenced by natural factors such as natural erosion, flow changes, benthic agitation, rocks weathering, etc. Besides, anthropogenic factors as atmospheric deposition, traffic emissions, terrestrial runoff, disposal of liquid effluents, agricultural runoff and fertilizer leaching, industrial wastewater discharge, and sewage discharge, etc. (Islam *et al.*, 2014; Iqbal *et al.*, 2016; Khallaf *et al.*, 2018a; Proshad *et al.*, 2019; Bibi *et al.*, 2020). Also, the HMs accumulation from water to sediment is linked to many external ecological factors. These are pH value, ionic strength, Eh, the level and type of inorganic and organic ligands, the possible adsorption surface area induced by the grain size distribution variation, and anthropogenic input (Davies *et al.*, 1991). In the aquatic ecosystem, sediments can subsequently act as a potential contaminants secondary source (Yu *et al.*, 2008; Bai *et al.*, 2011; Lin *et al.*, 2020). Because of chemical plus physical disorders, contaminants as HMs in sediments may be liberated into the water column, which implies that the sediments act as an essential sink and a long term release agent of HMs into the ecosystem even long after the initial input, which is of great importance for the aquatic system safety (Bing *et al.*, 2019). Sediments were used to detect insoluble pollutants and demonstrate the water system quality (Karthikeyan *et al.*, 2007; Lakshmanasenthil *et al.*, 2013). Sediment's HMs analysis enabled detecting contaminants that perhaps either at low levels or absent in the aquatic medium (Binning and Baird, 2001). So, the study on HMs in surficial sediments were found to give essential understandings into elemental pollution and related hazards to protect the aquatic environment (Iqbal *et al.*, 2016). The riverine sediments provided preferable documentation to evaluate the pollution and probable ecological hazard of HMs in the aquatic ecosystem, and indicated both spatial and temporal trends of contaminants (Bing *et al.*, 2019; Tan and Aslan, 2020). So, the sediment's HMs distribution analysis near inhabited regions could be used to examine anthropogenic influences on environments and help evaluate hazards caused by the wastes releases of humans (de Mora *et al.*, 2004; Zheng *et al.*, 2008; Yi *et al.*, 2011). Moreover, investigation of HMs in sediments of water environments is a substantial necessity to realize their influences on water and living organisms (Black and Williams, 2001; Elsayed *et al*. 2015, 2001; Ho and Hui, 2001).

So, the aim of the current work was as follows: (1) to explore the spatially and seasonally variations of the HMs (Al, Cr, and Mn) concentrations in the sediment samples collected from different sites of Bahr Shebeen Canal (BSC), Egypt; (2) to compare HMs concentrations in the sediment of BSC with those in other various Egyptian areas; (3) to compare HMs concentrations with the recommended international permissible limits and sediment quality guidelines; (4) to evaluate and assess HMs pollution level, potential ecological risk and the carcinogenic and non-carcinogenic human health risk of HMs in the sediment of BSC.

MATERIALS AND METHODS

1. Study area

Bahr Shebeen Canal (BSC), located in the delta originating from a major canal (Alrayah Almenoufi) of Egypt (Fig. 1), represents a vital fishery source and used for irrigation. It extends for about 80 Km passing through Menoufia, Gharbia, and Dakahlia governorates. It is an important, semi-independent ecosystem (30 m wide and 2-3 m deep) from the Nile **(Khallaf and Authman, 1992)**, BSC is surrounded by various villages, two major cities, and cultivated lands. Due to human interference (shore protection works), shore plants are rare, especially near towns, and on shores, macrophytes are prevalent **(Khallaf, 2002)**. No submerged plants are noticed during the water closure (embankment), which occurs in winter every year from 15 January to 15 February. The canal's bottom consisted mainly of silt, and sides/margins were regular and muddy **(Sheir, 2018)**.

2. Sediment sampling and pretreatment

Twenty-three surface bottom sediments (0–10 cm) samples, during the period from September 2014 till December 2015, were collected from 3 main sites (S1, S2, and S3) along several kilometers (2 km more/less). These sites were chosen over the BSC at Shebeen Alkoom City (30°53' and 30°58' N and 31°01' and 31°02' E), Menoufia Province, Egypt. The chosen sites were selected to symbolize different contaminated regions (near workshops, hospitals, agricultural fields, refuse centers, etc.). These sampling sites were chosen downstream to all the pollution points. The studied area water's environmental factors were previously mentioned in detail in **Khallaf *et al.* (2018a)**'s work. After collection using Ekman Dredge, the samples were put in dark bags for transportation to the laboratory and preserved frozen until the analyses. The sediment samples were brought to room temperature, dried in air, ground and homogenized in a mortar, and sieved to a fine powder.

3. Chemical analysis

Al, Cr, and Mn of sediment samples were treated according to **Kouadio and Trefry (1987)** method. In brief, 0.5 g of each sample was weighed and into a crucible and digested with a mixture of concentrated HNO_3+$HClO_4$+ HF. After cooling, the digestate was diluted to 50 ml with HNO_3. Al, Cr, and Mn concentrations were analyzed using Inductive Coupled Plasma-Optical Emission Spectrometry (ICP-AES, Agilent 720). The metal values are expressed as milligrams per kilogram dry weight (dw). Quality control protocols were previously mentioned in detail in the work of **Khallaf *et al.* (2018a)**. All digestion and the samples' analysis were carried out at the Egyptian Mineral Resources Authority, Ministry of Petroleum, Dokki, Egypt.

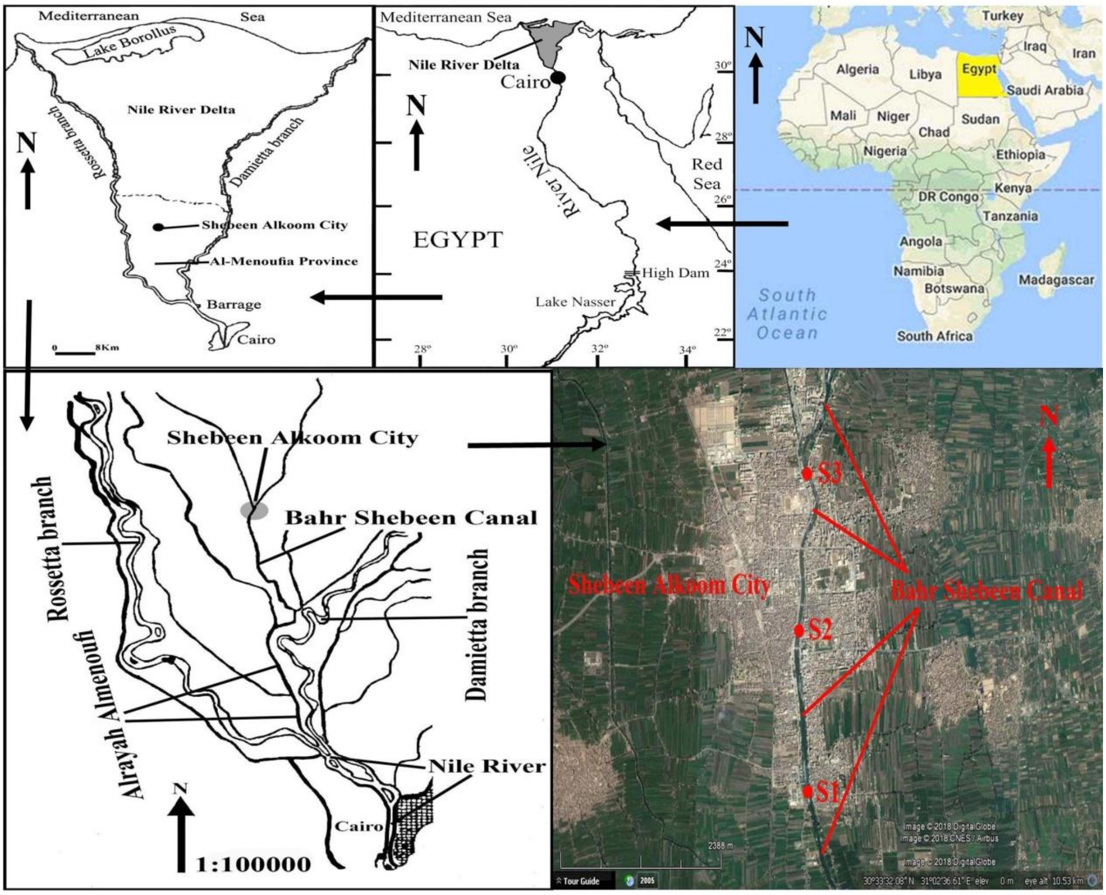

Fig. (1): Map showing the area of study (Bahr Shebeen Canal, BSC, in the Egyptian Delta).

4. Contamination indices of sediment

Some pollution indices were used to evaluate the contamination and ecological risk posed by the HMs contamination in sediments. These used indices were classified into two types, single and integrated indices. The descriptive terminologies for contamination classes on single and integrated indices were presented in table (1).

Table (1): The descriptive terminologies for HMs pollution classes on single and integrated indices.

Enrichment Factor (EF)[1]		Contamination Factor (CF)[2]	
EF value	Categories	CF value	Pollution
EF < 1	No enrichment	CF < 1	Low contamination
1 < EF < 3	Minor enrichment	1 ≤ CF ≤ 3	Moderated contamination
3 < EF < 5	Moderate enrichment	3 < CF < 6	Considerable contamination
5 < EF < 10	Moderately severe enrichment	CF ≥ 6	Very high contamination
10 < EF < 25	Severe enrichment		
25 < FE < 50	Very severe enrichment		

EF > 50	Extremely severe enrichment			
Potential contamination index (Cp)[3]		**Geo- accumulation index (I_{geo})[4]**		
Cp value	grade	*Igeo*	*Igeo* class	Pollution
Cp< 1	Low contamination	< 0-0	0	Unpolluted
1 <Cp< 3	Moderate contamination	> 0-1	1	Unpolluted to moderated
Cp> 3	Severe or very severe contamination	> 1-2	2	Moderated polluted
		> 2-3	3	Moderated to high polluted
		> 3-4	4	Highly polluted
		> 4-5	5	Highly to extremely polluted
		> 5-6	> 5	Extremely polluted
potential ecological risk coefficient (E_{rc})[5]		**Pollution Load Index (PLI)[6]**		
E_{rc}	grade	PLI		Pollution
E_{rc}<40	Low potential ecological risk	0		Perfection
40 ≤ E_{rc}< 80	Moderate potential ecological risk	≤ 1		Baseline levels
80 ≤ E_{rc}< 160	Considerable potential ecological risk	> 1		Polluted
160 ≤ E_{rc}< 320	High potential ecological risk			
E_{rc} ≥ 320	Very high ecological risk			
Degree of Contamination (DC)[7]		**Potential ecological risk index (RI)[8]**		
DC	Description	RI		grade
DC < 8	Low degree of contamination	RI < 150		Low ecological risk
8 ≤ DC < 16	Moderate degree of contamination	150 ≤ RI < 300		Moderate ecological risk
16 ≤ DC < 32	Considerable degree of contamination	300 ≤ RI < 600		Considerable ecological risk
DC ≥ 32	Very high degree of contamination	RI ≥ 600		Very high ecological risk

[1]**Sakan *et al.* (2009)**. [2]**Hakanson (1980)**. [3]**Dauvalter and Rognerud (2001)**. [4]**Müller (1969)**. [5]**Hakanson (1980)**. [6]**Tomlinson *et al.* (1980)**. [7,8]**Hakanson (1980)**.

4.1. The single indices

4.1.1. Enrichment factor (EF)

The EF is used to determine the anthropogenic HMs pollution degree. It is computed by using the **Sinex and Helz (1981)** equation:

$$EF = \frac{(M/Al)_{sample}}{(M/Al)_{background}}$$

Where, $(M/Al)_{sample}$ is the concentration ratio of the studied metal M to Al in sediment sample and $(M/Al)_{background}$ is their concentration ratio in the selected reference background. For geochemical normalization, Al was chosen to be the reference background element, in the current study, to minimize grain size effect while assessing metal distribution **(Gu *et al.*, 2013)**. Average crustal abundance **(Taylor, 1964)** and average shale values (ASV) **(Turekian and Wedepohl, 1961)** were frequently used to provide concentrations of elemental background. Because the reference background values of HMs in local BSC sediment during pre-industrial times have not been determined, so, the average shale values (ASV) **(Turekian and Wedepohl, 1961)**, and the Pre-Aswan High Dam concentrations (PAHDC) of the River Nile sediments **(Abu Khatita, 2011)** were used for the present study as background references (Table 2).

Table (2): Sediment quality guidelines (SQGs) and sediments classification used in the present study.

	Al	Cr	Mn
Sediment quality guidelines (SQGs)			
Shale standard[1]	80000	90	850
Earth Crust[2]	82300	100	950
PAHDC[3]	32206	58	276
LEL[4]	NA	26	460
TEL[4] (ISQG)	NA	37.3	NA
SEL[4]	NA	110	1110
PEL[4]	NA	90	NA
MET[4]	NA	55	–
ERL[4]	NA	80	NA
ERM[4]	NA	145	NA
TEC[4]	NA	56	1673
Cons-Based TEC[4]	NA	43.4	NA
PEC[4]	58030	159	1081
Cons-Based PEC[4]	NA	111	NA
TET[4]	NA	100	NA
USEPA sediments classification[5]			
Non-polluted	–	<25	<300
Moderately polluted	–	25 to 75	300 to 500
Heavily polluted	–	>75	>500

G. Avg. = grand average. NA = not available. PAHDC = Pre Aswan High Dam concentrations.

LEL = Lowest effect level; TEL = Threshold effect level; SEL = Severe effect level; PEL = Probable effect level; MET = Minimal effect threshold; ERL = effect range-low; ERM = effect range-median, TEC = Threshold effect concentration; Cons-Based TEC = Consensus-based threshold effect concentrations; PEC = Probable effect concentration; Cons-Based PEC = Consensus-based probable effect concentrations; TET = Toxic effect threshold; ISQG = Interim Sediment Quality Guidelines.

1Turekian and Wedepohl (1961). 2Taylor (1964). 3Abu Khatita (2011). 4Persaud et al. (1993); Jones et al. (1997); MacDonald et al. (2000); CCME (2012). 5Giesy and Hoke (1990).

4.1.2. Contamination factor (CF)

CF is the ratio of the metal content in the studied sediment to the background level of the same metal and obtained **(Hakanson, 1980)** by the following equation:

$$CF=\frac{M_x}{M_b}$$

Where M_x is the concentration of the metal in the sample, and M_b is its content in the designated background reference.

4.1.3. The potential contamination index (Cp)

Cp was introduced by **Dauvalter and Rognerud (2001)** as follows:

$$Cp = \frac{(Metal)_{Sample\ max}}{(Metal)_{Background}}$$

Where: $(Metal)_{Sample\ max}$ is the maximum metal concentration in the sediment sample and $(Metal)_{Background}$ is the same metal average value in a background reference.

4.1.4. Geo-accumulation index (I_{geo})

I_{geo} has been applied to the assessment of any metal contamination in sediment by comparing its current concentration with its pre-industrial level. In the present work, I_{geo} values were calculated **(Müller, 1969)** as follows:

$$Igeo = \log_2 \left(\frac{C_n}{1.5\ B_n}\right)$$

Where: C_n is the content of any studied metal (n) in the sample and B_n is its geochemical background reference value in pre-industrial (pre-civilization) reference [ASV **(Turekian and Wedepohl, 1961)** and PAHDC **(Abu Khatita, 2011)**]. Factor 1.5 is introduced to reduce probable variations in the background values that are because of the lithogenic effects, besides the very small anthropogenic influences **(Qingjie *et al.*, 2008)**.

4.1.5. The potential ecological risk factor of a single heavy metal (E_r)

E_r can be computed **(Hakanson, 1980)** via the following equations:

$$E_r = T_r \text{ X } CF$$

Where: CF is a single element contamination factor, and T_r is the same element toxic response factor, which represents the requirements of environmental toxicity and sensitivity. The Cr and Mn toxic response factors were 2 and 1, respectively **(Hakanson, 1980; Xu *et al.*, 2008)**.

4.2. The integrated indices

4.2.1. The pollution load index (PLI)

PLI suggested by **Tomlinson *et al.* (1980)** is a comparative mean for evaluating the HMs pollution level between different sites and times. It is given in the following equation:

$$PLI = (CF1*CF2*CF3 *\ldots CFn)^{1/n}$$

Where n is the number of the metal (3 here), and CF is each single metal contamination factor.

4.2.2. The degree of contamination (DC)

DC for a specified site is the summation of its all contamination factors. It is computed **(Hakanson, 1980)** as follows:

$$DC=\sum_{i=1}^{n} CF$$

Where CF is the single contamination factor and n is the number of the metal.

4.2.3. The potential ecological risk index (RI)

RI is a method proposed, from a sedimentological perspective, by **Hakanson (1980)** to evaluate the environmental behaviour and characteristics of HMs contaminants in sediments. It is computed as the summation of all potential ecological risk factors (E_r) for HMs in sediment as follows:

$$RI=\sum_{i=1}^{n} E_i$$

Where: E_r = the potential ecological risk factor of a single element and n is metals number.

5. Sediment quality guidelines (SQGs) and sediment classification

SQGs assist in expecting the contaminated sediments antagonistic biological influences on aquatic organisms and are purposed for the sediment quality clarification **(Long *et al.*, 1995; MacDonald *et al.*, 2000; Maanan *et al.*, 2015)**. The dependability of the TEC (threshold effect concentration), Cons-TEC (consensus-based threshold effect concentrations), PEC (probable effect concentration), Cons-PEC (consensus-based probable effect concentrations), LEL (lowest effect level), TEL (threshold effect level), ERL (effect range low), MET (minimal effect threshold), SEL (severe effect level), PEL (probable effect level), ERM (effect range-median) and TET (Toxic effect threshold) (Table 2) for assessing sediment quality conditions is determined based on their predictive ability **(Persaud *et al.*, 1993; MacDonald *et al.*, 2000)**. USEPA has characterized three sediment evaluations **(Giesy and Hoke, 1990)**, in which the concentration of definite HMs is regarded as factors used to classify the quality of sediments (Table 2).

6. Human health risk assessment of intake of HMs through dermal contact pathway

There is a sub-human population exposes directly to the sediments during fisheries, agriculture and other activities **(Mahmoud *et al.*, 2017)**. HMs dermal contact from contaminated aquatic sediments has extraordinary significance in probable exposure pathways **(Proshad *et al.*, 2019)**. $CDI_{dermal\text{-}sediment}$ (Chronic daily intake via dermal contact) is properly evaluated using site-specific data for the population at danger. The evaluating of HMs absorption by dermal contact exposure way of metals in the sediments **(USEPA, 2007; Qing *et al.*, 2015)**, is calculated by this next mathematical equation:

$$CDI_{dermal\text{-}sediment} = \frac{CS \times SA \times AF \times ABS \times EF \times ED}{BW \times AT} \times CF$$

Where: $CDI_{dermal-sediment}$ is HMs chronic daily intake (mg kg^{-1}) from sediment by dermal contact. Other values and factors of exposure mentioned in the above equation in the current study are listed and explained in table (3).

Also, current work assessed the non-carcinogenic and carcinogenic influences of HMs from the dermal exposure to contaminated sediments through the HQ (hazard quotient), HI (hazard index) and CRI (carcinogenic risk index) methods **(Chabukdhara and Nema, 2013; Wei *et al.*, 2015)**.

The HQ is expressed by the ratio of the CDI to RfD (the reference daily dose) for each metal **(USEPA, 1989)**, by the following formula **(Qing *et al.*, 2015)**:

$$HQ_{dermal-sediment} = \frac{CDI}{RfD}$$

Where RfD (mg/kg day) is the maximum absorbed daily dose of a metal via dermal contact, for both children and adults, that is supposed not to lead to an significant hazard of harmful effects to sensitive persons during a life span. The RfD_{dermal} for Al, Cr, and Mn were 1.00E-01, 6.00E-05 and 1.84E-03 mg/kg/day, respectively **(USEPA, 2002; USDOE, 2019)**. When CDI<RfD, then HQ≤1, so it is believed that no severe human health effects will occur, while if the CDI>RfD, then HQ>1, so it is possible that severe human health effects will occur **(USEPA, 1989; USEPA, 2001)**.

Table (3): Exposure factors of dermal contact for health risk assessment of HMs in sediments.

Factor	Definition	Unit	Value		Reference
			Children	Adults	
CS	Heavy metal concentration in sediment	mg kg^{-1}			This study
SA	Exposure skin surface area available for contact	cm^2	1600	5700	**USEPA (2011)**
AF	Sediment-to-skin adherence factor	mg/cm^2	0.2	0.7	**USEPA (2011)**
ABF	Dermal absorption factor	—	0.001	0.01	**USEPA (2011)**
EF	Exposure frequency	days/year	350	350	**USEPA (2011)**
ED	Exposure duration	years	6	24	**USEPA (2001)**
BW	Average body weight of the exposed individual	Kg	15	60	**USEPA (1989)**; **Chabukdhara and Nema (2013)**
AT	Average time for non-carcinogens	days	365 x ED	365 x ED	**USEPA (2011)**
CF	Conversion factor	kg/mg	1×10^{-6}	1×10^{-6}	**USEPA (2002)**

The HI could be produced from the HQ values to compute the joint hazard of single HMs in the form of a mixture of pollutants **(USEPA, 1989; Qing *et al.*, 2015)**. HI of dermal exposure way could be computed by the next formula **(Qing *et al.*, 2015)**:

$$HI_{dermal-sediment} = \sum HQ_n = \text{HQ element1} + \text{HQ element 2} \ldots\ldots\ldots \text{HQ elements n}$$

When HI<1, then it is believed that no hazard of non-carcinogenic influences will happen, while if HI>1, this showed the possibility of harmful health influences, and the possibility increases with the HI values increases.

Carcinogenic risk index (CRI) is considered as the possibility of a person developing any cancer type in the entire life as a result of carcinogenic hazards exposure **(Li *et al.*, 2014)**. CRI is calculated **(Qing *et al.*, 2015)** as follows:

$$CRI = \Sigma\, CDI_i \times SF_i$$

Where: SF is the cancer slope factor (mg/kg-day) of individual metal which represents the possibility of developing cancer per unit exposure level. The values of SF for Al and Mn were not available, whereas SF value for Cr was 4.2E+01 **(Qing *et al.*, 2015)**, so only CRI for Cr was estimated. If CRI<10^{-6}, so the carcinogenic risk from the sediment to health can be negligible, whereas a CRI above 1 X 10^{-4} is likely to be a high risk of developing cancer in human beings. CRI values in the range from 1 X 10^{-6} to 1 X 10^{-4} indicate an acceptable or tolerable risk to social stability and to human health **(Wu *et al.*, 2015)**.

7. Statistical analysis

Basic descriptive statistics of HMs concentrations in sediment were performed to calculate means and standard errors (SE). One-way ANOVA analysis, followed by a post hoc comparison using Duncan's multiple ranges **(Duncan, 1955)**, was applied to determine the variance's position and identify significant differences for all metals. All statistical analyses were done using the computer program of SPSS Inc. (version 17.0 for Windows) at the P<0.05 and 0.01 levels of significance, and graphs were plotted with Microsoft Excel 2010.

RESULTS AND DISCUSSION

1. Spatial and seasonal concentrations of HMs in the sediments

Sediments, in addition to water, can be considered as a sensitive indicator during aquatic habitat quality monitoring **(Bastami *et al.*, 2015)**. Contaminants in sediments constitute a hazard to the environment in the following two primary ways: (1) environmental risk to fish-eating and aquatic animals and (2) toxic hazards on terrestrial habitat when the polluted area is dredged and put on land **(Khan *et al.*, 2000)**. The spatial and seasonal Al, Cr, and Mn average concentrations in the BSC sediments (Table 4) showed that Al has the highest mean concentrations followed by Mn, whereas Cr has the lowest mean levels. The comparatively high Al value of sediments reflects the abundance of this element as a major component of clay minerals **(Korium *et al.*, 2006)**. This is because Al and Fe are the most common metals in Earth's crust and is also confirmed with that reported by **Abdel-Satar (2005)** and **Khallaf *et al.* (2018a)** on River Nile and BSC sediment, respectively. Also, **Mookherjee (2018)** mentioned that Al in the Earth's crust is the third most plentiful element. The wide ranges of Al, Cr, and Mn concentrations at different sites may be ascribed to: (1) the texture and particle size of the sediment, (2) the organic matter content **(Anonymous, 1997)**, (3) the mud percent variations, and (4) the increase in heavy metal-rich urban wastes draining into Nile River **(Abdel-Satar, 2005; El-Gamal, 2016)**. Adding to that, the higher values of Al, Cr, and Mn are possibly because of the decay of organic materials, agricultural wastes, fertilizers, insecticides, sewage, and illegal wastewater discharges, where BSC receives variable amounts of municipal wastewaters. It is probably associated with the municipal wastes of the nearby city (Shebeen Alkoom City). Spatially, statistical analysis revealed that concentrations of Al, Cr, and Mn showed significant (P<0.05) differences between sites. The relatively significant high levels reflect likely anthropogenic point-source of these elements at these locations **(Oyewumi *et al.*, 2017)**. The coefficients of variation (CVs) showed that Cr has the highest value, followed by Mn and finally Al, with the CVs of 28.43, 25.70, and 22.97%, respectively. These indicate that the metals total concentrations vary between the three sampling sites **(Soliman *et al.*, 2019)**, which may be caused by anthropogenic inputs of HMs **(Huang *et al.*, 2019)**. It was found that Site S1 showed the Al, Cr, and Mn highest mean values (Fig. 2A-C). This is showing that this site is comparatively more polluted with these metals compared to other sampling sites, and this is because the extensive discharging of urban waste drove HMs pollution in surface sediment **(Khallaf *et al.*, 2018a; Proshad *et al.*, 2019)**. The urban activities like household refuse, municipal wastewater, urban runoff, and industrial discharges are the main higher metal input sources at S1. The levels of total HMs contamination at different sites are arranged in Site S1> Site S3 > Site S2 for Al and Mn, whereas for Cr, it is arranged in the order of Site S1> Site S2 > Site S3. Seasonally, only Cr and Mn concentrations showed a difference ($P<0.05$) between seasons significantly. The levels of Al concentrations are arranged in the following order: summer>winter> autumn> spring, whereas the Cr and Mn levels are arranged in the following order: winter>autumn> spring>summer (Fig. 2D-F). Previously, **Alnenaei and Authman (2010)** reported that Al is released into aquatic ecosystems through the recycled Al industries emissions and the stations of water purification discharge that contain an enormous amount of Al sulfate (alum), which are used as suspended solid particles coagulant. Also, higher concentrations of Al were detected in some drainage canals water in Menoufia Province, Egypt **(Authman, 2008; Authman *et al.*, 2008; 2011)**, which may finally find its way into BSC. The higher Cr values during winter attributed to the higher pH and dissolved oxygen during this period caused the oxidation of Cr^{2+} to Cr^{4+} and dissolution from water to sediment. Besides, Cr can precipitate from water to bottom sediment as carbonate or hydroxide resulted in the increasing pH value during the winter period **(Korium *et al.*, 2006)**. High Cr concentration in sediments has been related to industrial wastes (as tanneries and textile factories) and sewage wastewater discharge **(Singh *et al.*, 2004; 2010; Mohiuddin *et al.*, 2011)** from the towns and villages located within BSC catchment. **Vasiliu and Dixon (2018)** mentioned that the main human activities that increase chromium concentrations are electro painting and textile, leather, and chemical manufacturing. On the other hand, the low Cr values recorded in the summer season may be related to the higher water temperature. Consequently, the decreases in dissolved oxygen caused the Cr release from sediment to overlying water **(Korium *et al.*, 2006)**. High Mn concentration in sediments has been related to cosmetics, medical imaging agents, dry-cell batteries, paints, and fertilizers **(ATSDR, 2012)** present in refuse, traffic emissions, and sewage wastewater discharge from the towns and villages located within BSC catchment. The relatively higher Mn values were measured in winter due to Mn's precipitation from water to sediment as carbonate form **(Korium *et al.*, 2006)**. **Gerke and Little (2018)** reported that Mn carbonates are insoluble. Besides, higher concentrations of Cr and Mn during winter than in summer may be attributed to the water's lower flow in winter, which could help to the HMs accumulation in sediment **(Mohiuddin *et al.*, 2011; Islam *et al.*, 2014)**. Adding to that, the Mn contents lower values during summer due to the dissolution of Mn hydroxides and oxides to the overlying water under low dissolved oxygen values and high water temperatures **(Elewa, 1993)**. The slight increase in Cr and Mn concentrations in sediment during the spring period might be ascribed to the direct agricultural and industrial wastes inputs discharging into the River Nile **(Osman *et al.*, 2012)**.

Table (4): Spatial and seasonal variations of Al, Cr and Mn concentrations (mgkg^{-1} dw) in sediment samples collected from different sites along BSC.

Sites	Aluminum (Al)						Chromium (Cr)						Manganese (Mn)					
	Range			Mean	±	SE	Range			Mean	±	SE	Range			Mean	±	SE
Site 1	52959.800	–	82470.000	67027.542	±	1794.092[b]	86.622	–	131.026	105.356	±	2.670[b]	712.339	–	1095.530	891.353	±	28.333[b]
Site 2	31451.000	–	65111.500	51033.150	±	2551.818[a]	24.331	–	126.350	79.051	±	5.483[a]	332.416	–	1058.170	745.990	±	44.059[a]
Site 3	37051.500	–	69262.500	53242.795	±	2598.473[a]	49.585	–	109.516	74.185	±	4.297[a]	566.623	–	1223.250	886.411	±	56.225[b]
G. Avg.	31451.000	–	82470.000	57268.917	±	1583.583	24.331	–	131.026	86.719	±	2.968	332.416	–	1223.250	839.288	±	25.964
F-value				14.311						15.221						3.722		
Sig.				0.000**						0.000**						0.029*		
Seasons	**Aluminum (Al)**						**Chromium (Cr)**						**Manganese (Mn)**					
	Range			Mean	±	SE	Range			Mean	±	SE	Range			Mean	±	SE
Spring	32447.000	–	63102.700	47638.567	±	6429.144[a]	65.348	–	107.994	86.241	±	9.123[b]	712.339	–	730.215	721.941	±	2.620[ab]
Summer	31451.000	–	82470.000	60445.267	±	7351.102[b]	24.331	–	103.901	62.731	±	11.359[a]	332.416	–	1067.130	661.776	±	106.201[a]
Autumn	37051.500	–	76799.000	57654.050	±	1806.029[ab]	49.585	–	126.350	90.203	±	3.008[b]	585.675	–	1223.250	874.061	±	29.583[b]
Winter	39617.900	–	71488.000	58120.594	±	2465.475[ab]	54.214	–	131.026	91.906	±	6.274[b]	566.623	–	1143.190	897.613	±	50.392[b]
G. Avg.	31451.000	–	82470.000	57268.917	±	1583.583	24.331	–	131.026	86.719	±	2.968	332.416	–	1223.250	839.288	±	25.964
F-value				1.299						3.752						3.791		
Sig.				0.282†						0.015*						0.014*		

Data are expressed as mean ± standard error (SE)

Means with the same letter at the same column are not significantly different (P>0.05).

G. Avg. = grand average. *F*-value = ANOVA's *F*-test. Sig. = significance level.

*Significant (P<0.05). **Highly significant (P<0.01). †Insignificant (P>0.05).

2. Source variation of HMs in the sediments

Pearson correlation analysis showed that Al has a highly significant positive correlation with Cr and Mn (r = 0.693 and 0.505, P<0.01, respectively). **Bing *et al.* (2019)** mentioned that Al contained in clay minerals could adsorb HMs in sediments. Cr showed a highly significant positive correlation with Mn (r = 0.592, P<0.01). A higher correlation coefficient between the metals may indicate the similar distribution pattern of these metals and/or may reveal the same pollution levels, mostly produce from similar pollution origins (either anthropogenic and geogenic), and also move together **(Batayneh *et al.*, 2015; Al-Alimi and Alhudify, 2016; El-Radaideh *et al.*, 2017; Proshad *et al.*, 2019)**. The overall order of profusion of heavy metals of interest in BSC sediments is Al>Mn>Cr (Fig. 2G).

3. Contamination assessment and pollution indices of HMs in the sediments

When compared with the average shale values (ASV) [geochemical background] of HMs **(Turekian and Wedepohl, 1961)**, Earth's Crust **(Taylor, 1964)** and the PAHDC of the River Nile sediments **(Abu Khatita, 2011)** (Table 2), it was found that the Al, Cr, and Mn concentrations in some BSC sediments samples, in this investigation, were higher than these background references, which indicated the contamination of BSC sediments by these HMs. These findings also suggest that the early stage identifies these metals' anthropogenic pollution to the BSC area. The BSC sediments have higher or lower levels of Al, Cr, and Mn concentrations compared (Table 5) with those reported studies of other regions in Egypt. Generally, the estimated levels of metals in the current work were comparatively greater than the previously published articles. Differences between present results and the other literature perhaps originate from variations in the localities geological mining history and domestic and urban activities **(Yehia and Sebaee, 2012)**.

The indices of pollution are used to determine the probable adverse effects intensity that could happen in an ecosystem exposed to contaminant stress **(Qingjie *et al.*, 2008)**. In the current study, pollution indices were calculated based on the background of HMs in ASV **(Turekian and Wedepohl, 1961)** and the PAHDC of the River Nile sediments **(Abu Khatita, 2011)**. EF (Enrichment factor) is a standardization method commonly applied to classify the portions of metal linked with the sediments **(Huang *et al.*, 2014; Proshad *et al.*, 2019)**. EF is used to distinguish between metals arising from anthropogenic or natural activities **(Manoj and Padhy, 2014; Al-Taani *et al.*, 2015)**. It was found that all metals were in no or minor enrichment at all stations and during different seasons (Tables 6 and 7). Generally, the studied metals average EF in the BSC sediments displayed contamination order of Mn>Cr>Al according to ASV and Mn>Al>Cr according to PAHDC. This is showed that Mn is the most abundant and enriched metal from anthropogenic activities, which is ascribed to refuse, fertilizer, sewage, and raw agricultural and industrial effluents. **Sakan *et al.* (2009)** reported that values of EF from 0 to 1 show that the metal comes totally from crustal materials or natural processes, while values of EF more than 1 show that the origins are more possibly to be anthropogenic **(Maanan *et al.*, 2015)**. The Cr and Mn EF values, in current work, revealed that EF > 1 indicates their enrichments. This suggests that the studied metals maybe came from non-crustal materials and/or non-natural weathering processes **(Gao and Chen, 2012; Islam *et al.*, 2015; Proshad *et al.*, 2019)** and were probably originated from human influence (anthropogenic inputs). The contamination factor (CF) determination of HMs is a vital aspect that shows the risk degree of HMs to an ecosystem in relation to its retention time **(Wu *et al.*, 2010; Buhari and Ismail, 2016)** and to express the contamination level **(Pekey *et al.*, 2004; Barik *et al.*, 2018)**. The CF values of all metals, in current work, were in low, moderate, and considerable pollution at all sites and during different seasons (Tables 6 and 7). Generally speaking, CF's values were arranged in descending arrangement of the average as follows: Mn>Cr>Al according to ASV and Mn>Al>Cr according to PAHDC. The high CF value of HMs shows low retention time and high hazard to the environment **(Wu *et al.*, 2010; Buhari and Ismail, 2016)**. Potential contamination index (Cp) shows that all HMs are at low, moderate, severe and/or very severe contamination levels at sampling sites and during different seasons. All HMs showed different degrees of anthropogenic influence according to the Cp values of the BSC sediments. Overall Cp values (Tables 6 and 7) were arranged in descending order of the average as follows: Mn>Cr>Al according to ASV and Mn>Al>Cr according to PAHDC. The geo-accumulation index (I_{geo}), suggested by **Müller (1969)**, deals with a common method to calculate the metal concentrations enrichment above background or baseline concentrations level. The I_{geo} values (Tables 6 and 7) vary according to metal type and spatially inside the BSC. According to the **Müller (1969)** scales, the negative values of I_{geo} indicated that the BSC sediment could be described as uncontaminated sediment with the studied metals, with some exceptions. According to the I_{geo} index, site S1 is the most impacted site with Mn classified as moderately polluted, Al and Cr considered unpolluted to moderately polluted. Site S3 comes next with Mn classified as moderately polluted, Al considered unpolluted to moderately polluted, whereas Cr considered unpolluted. At site S2, Al and Mn were classified as unpolluted to moderately polluted, whereas Cr was classified as unpolluted according to the I_{geo} index. Based on the I_{geo} values (Tables 6 and 7), the trace metals are arranged in the descending rank of the average as follows: Mn>Cr>Al according to ASV and Mn>Al>Cr according to PAHDC. The potential ecological risk factor (E_r) in the sediments (Tables 6 and 7) indicated that all the Cr and Mn mean E_r values were lower than 40 (i.e., E_r<40), which showed low ecological risk **(Hakanson, 1980)**. Based on the E_r values, the trace metals are arranged in the next descending rank of the average as follows: Cr>Mn according to ASV and Mn>Cr according to PAHDC. Seasonally, E_r values were arranged in descending order: winter> autumn> spring> summer. The DC (degree of contamination) values indicate that the sediments of BSC have a low degree of contamination (Tables 6 and 7) based on **Hakanson (1980)** scale. DC values were arranged in descending order of the average as follows: S1>S3>S2 and winter> autumn> spring> summer. Pollution Load Index (PLI) is a powerful method by which the complete risks of HMs could be assessed **(Tomlinson *et al.*, 1980)**. It also offers to analyzing, process, and conveying relevant ecological data to policy managers, makers, technicians, and the community **(Harikumar and Jisha, 2010; Mohiuddin *et al.*, 2010)**. The PLI can supply some understanding of the aquatic ecosystem quality that influences the residents **(Ali *et al.*, 2016)**. Furthermore, it also gives important data about the area of study pollution status that helps decision-makers make any decision **(Suresh *et al.*, 2011)**. PLI values in different sites showed that Site S1 has the highest value of PLI, which indicates the pollution of this site. S3 comes next and finally S1 with the lowest PLI value. According to PAHDC **(Abu Khatita, 2011)**, the canal's PLI indicated that the BSC sediments are polluted (Tables 6 and 7). PLI values were arranged in descending order of the average as follows: S1>S3>S2 and winter> autumn> spring> summer. During different seasons, the three sites were at a low-risk level of pollution where the RI (potential ecological risk index) values were much lower than 150 (Tables 6 and 7) as mentioned by **Hakanson (1980)**. RI values were arranged in descending order of the average as follows: S1>S3>S2 and winter> autumn> spring> summer.

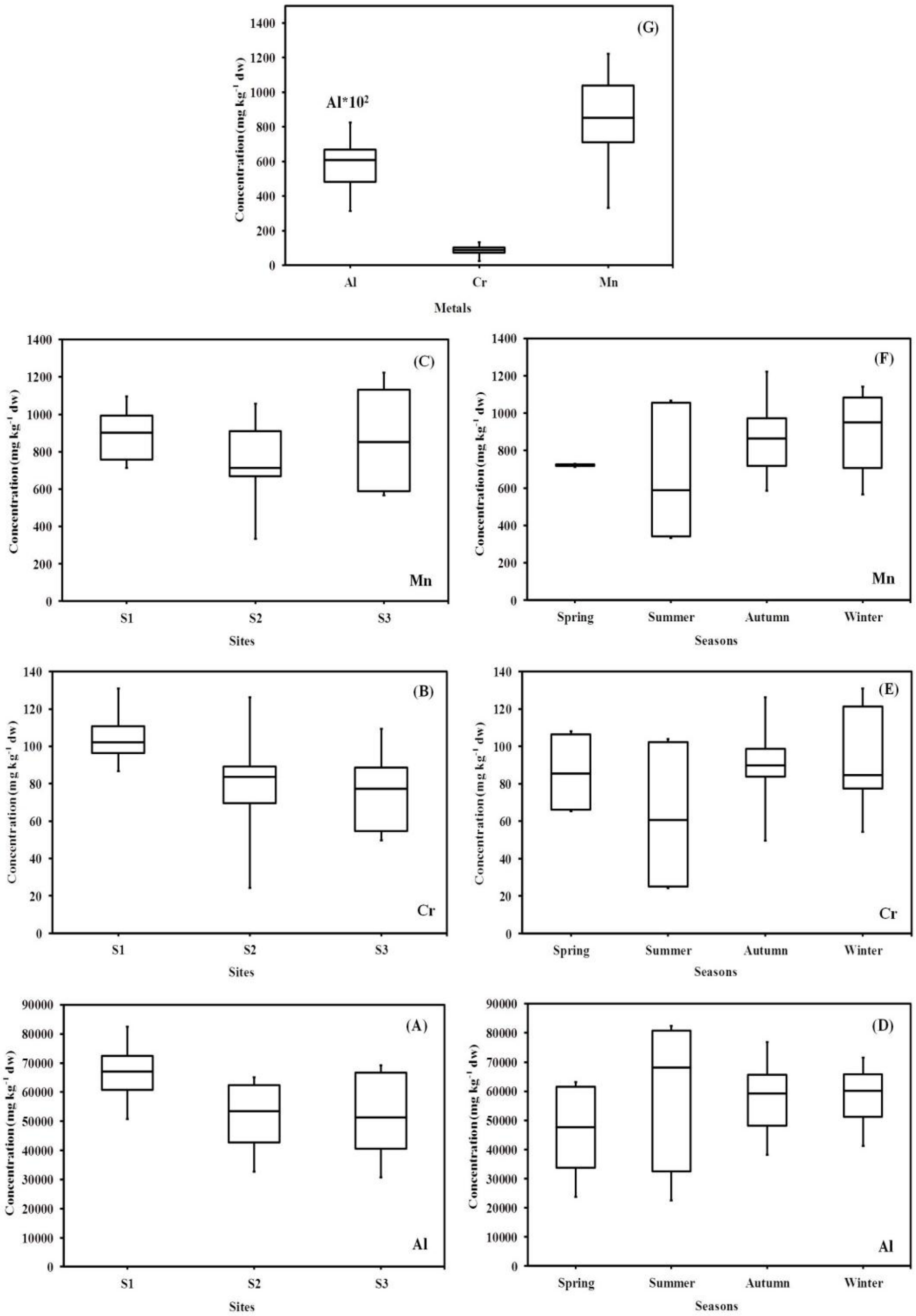

Fig. (2): Box and whisker plots of the spatial (A-C), seasonal (D-F) and total mean variations of Al, Cr and Mn concentrations in sediment of BSC.

Table (5): Comparison of HMs concentrations (mgkg^{-1} dw) in sediments of BSC with other Egyptian regions.

Location	Al	Cr	Mn	References
Bahr Shebeen Canal, Minoufiya governorate	31451–82470	24.33–131.03	332.42–1223.25	Present study
River Nile at Aswan	51.73-25716.32	44.0l-1140.9	0.0-2204.01	**Korium *et al.* (2006)**
River Nile at Aswan	–	8.8	210.36	**Osman and Kloas (2010)**
River Nile at Kena	–	11.1	159.84	**Osman and Kloas (2010)**
River Nile at Assiut	–	-	72.5-98.6	**Mekkawy *et al.* (2008)**
River Nile at Assiut	–	17.6	273.35	**Osman and Kloas (2010)**
River Nile at Beny-Suef	–	10.3	221.72	**Osman and Kloas (2010)**
River Nile at Beny-Suef	–	15.15	–	**Mahmoud *et al.* (2017)**
River Nile from Idfo to Cairo	–	–	94-2425	**Abdel-Satar (2005)**
Nile River at Greater Cairo district	–	38-46	290-640	**Lasheen and Ammar (2009)**
Nile Delta Barrage on Rosetta Branch	12365.5	92.50	225.19	**El Bouraie *et al.* (2010)**
Rosetta branch of River Nile	–	8.7	269.96	**Osman and Kloas (2010)**
Damietta branch of River Nile	–	9.1	351.79	**Osman and Kloas (2010)**
Lake Nasser	–	109.4	567.57	**Soltan *et al.* (2005)**
Lake Nasser	–	30.79	279.6	**Goher *et al.* (2014)**
Lake Manzala	17,348-40,455	10.64-44.22	295-582	**Elkady *et al.* (2015)**
Lake Qarun	350.31–671.35	54.7–143.31	–	**Soliman *et al.* (2018)**
Lake El Temsah	–	12.90–70.84	123.56–642.37	**Soliman *et al.* (2019)**

4. Sediment quality guidelines (SQGs) and sediments classification

SQGs are used to estimate the adverse biological influences of HMs in sediments and give for permissible concentrations of toxic elements to protect the organisms living in or near sediments **(MacDonald *et al.*, 2000; Palma *et al.*, 2015; Wu *et al.*, 2017)**. The concentrations of HMs in the collected BSC sediment samples, the current study, were compared with LEL, TEL, TEC, ERL, MET, Cons-Based TEC, SEL, PEL, ERM, TET, PEC, and Cons-Based PEC values (Table 2). Al was higher than PEC in 56.52% of samples. Cr was greater than LEL, TEL, MET, ERL, TEC, Cons-Based TEC, SEL, PEL, TET, and Cons-Based PEC in 95.65, 95.65, 86.96, 68.12, 86.96, 95.65, 13.04, 43.48, 30.43 and 13.04% of samples, respectively. Mn was higher than LEL, SEL, and PEC in 95.65, 10.15, and 15.94% of samples, respectively. Based on the SQGs, the adverse impacts on aquatic biota cannot happen when the concentrations of HMs are underneath the TEL, whereas it may occur as the concentrations reach the PEL **(Macdonald *et al.*, 1996; Smith *et al.*, 1996)**. The Cr concentrations in BSC sediments exceeded the levels of TEL. In their study on sediments of the Beisan River, Tianjin, **Qi *et al.* (2013)** proposed Mn values of 460 mg/kg and 1,100 mg/kg for TEC and PEC, respectively, so these values have been used for current work. In the present study, at all three sampling sites, Mn concentrations in some sediment samples exceed the TEC (Table **.**2), whereas some sediment samples at site S3 exceed the PEC. According to the USEPA sediments classification (Table 2), generally, it was observed that 4.35% of the collected sediment samples were non-polluted with Cr; 21.74% and 4.35% of samples were moderately-polluted with Cr and Mn, respectively, while 73.91% and 95.65% of sediment samples were heavily polluted with Cr and Mn, respectively. Present results revealed that the examined metals concentrations might be related to biologically adverse health effects to sediment-dwelling biota **(MacDonald *et al.*, 2000)**.

5. Human health risk assessment

The dermal contact of HMs in sediment is regarded as an important exposure pathway. There are many means to expose to metals due to sediment dermal contact as playing, wading, working, etc. **(Proshad *et al.*, 2019)**. The calculated CDI (chronic daily intakes) (Table 8) of the measured metals by dermal contact showed that CDI of Al, Cr, and Mn was lower than the values of dermal RfD for adult and children at different sites and during different seasons except for Cr in case of the adult at Site 1. So, there is a probability of developing non-carcinogenic hazard due to dermal exposure of Cr for the adult at this site. The potential non-carcinogenic lethal influences caused by HMs are commonly distinguished by hazard quotient (HQ) calculation. A glance at table (8) revealed that Al, Cr, and Mn have HQ values; as a result of dermal contact; lower than 1 (i.e., HQ<1) for adult and children at different sites and during different seasons except for Cr in case of the adult at Site 1. This proposes that there may be non-carcinogenic adverse health influence to adults via dermal absorption way on over Cr exposure at this site, indicating non-carcinogenic risk to adults. Due to the exposure to metals and metalloids, the collective effects were computed as HI (hazard index) **(Qing *et al.*, 2015)**. Table (8) showed that the HI values; at different sites and during different seasons; were higher than one (HI>1) for adults, whereas HI values for children were lower than one (HI<1). Therefore, there was a possibility of having a non-cancer hazard for Al, Cr, and Mn on adult health via dermal contact exposure to BSC sediments indicating pose non-cancer risk. In contrast, there was no non-carcinogenic risk for children.

Table (6): Results of the single and integrated pollution indices of the measured HMs in BSC sediment at different studied sites.

	According to ASV **(Turekian and Wedepohl, 1961)**						According to PAHDC of the River Nile sediments **(Abu Khatita, 2011)**					
Sites	Al		Cr		Mn		Al		Cr		Mn	
	EF	Rank	EF	Rank	EF	Rank	EF	Rank	EF	Rank	EF	Rank
Site 1	1.000	No enrichment	1.414	Minor	1.255	Minor	1.000	No enrichment	0.883	No enrichment	1.555	Minor
Site 2	1.000	No enrichment	1.364	Minor	1.383	Minor	1.000	No enrichment	0.852	No enrichment	1.714	Minor
Site 3	1.000	No enrichment	1.260	Minor	1.626	Minor	1.000	No enrichment	0.787	No enrichment	2.015	Minor
G. Avg.	1.000	No enrichment	1.350	Minor	1.412	Minor	1.000	No enrichment	0.843	No enrichment	1.751	Minor
Sites	Al		Cr		Mn		Al		Cr		Mn	
	CF	Rank	CF	Rank	CF	Rank	CF	Rank	CF	Rank	CF	Rank
Site 1	0.838	Low	1.171	**Moderate**	1.049	**Moderate**	2.081	**Moderate**	1.816	**Moderate**	3.230	**Considerable**
Site 2	0.638	Low	0.878	Low	0.878	Low	1.585	**Moderate**	1.363	**Moderate**	2.703	**Moderate**
Site 3	0.666	Low	0.824	Low	1.043	**Moderate**	1.653	**Moderate**	1.279	**Moderate**	3.212	**Considerable**
G. Avg.	0.716	Low	0.964	Low	0.987	Low	1.778	**Moderate**	1.495	**Moderate**	3.041	**Considerable**
Sites	Al		Cr		Mn		Al		Cr		Mn	
	Cp	Pollution	Cp	Pollution	Cp	Pollution	Cp	Pollution	Cp	Pollution	Cp	Pollution
Site 1	1.031	**Moderate**	1.456	**Moderate**	1.289	**Moderate**	2.561	**Moderate**	2.259	**Moderate**	3.971	**Severe or very severe**
Site 2	0.814	Low	1.404	**Moderate**	1.245	**Moderate**	2.022	**Moderate**	2.172	**Moderate**	3.833	**Severe or very severe**
Site 3	0.866	Low	1.217	**Moderate**	1.439	**Moderate**	2.151	**Moderate**	1.897	**Moderate**	4.431	**Severe or very severe**
G. Avg.	1.031	**Moderate**	1.456	**Moderate**	1.439	**Moderate**	2.244	**Moderate**	2.109	**Moderate**	4.079	**Severe or very severe**
Sites	Al		Cr		Mn		Al		Cr		Mn	
	Igeo	Rank	*Igeo*	Rank	*Igeo*	Rank	*Igeo*	Rank	*Igeo*	Rank	*Igeo*	Rank
Site 1	-0.852	Unpolluted	-0.368	Unpolluted	-0.533	Unpolluted	0.460	Unpolluted to moderated	0.266	Unpolluted to moderated	1.089	**Moderated polluted**
Site 2	-1.281	Unpolluted	-0.888	Unpolluted	-0.844	Unpolluted	0.032	Unpolluted to moderated	-0.254	Unpolluted	0.779	Unpolluted to moderated
Site 3	-1.208	Unpolluted	-0.912	Unpolluted	-0.586	Unpolluted	0.105	Unpolluted to moderated	-0.278	Unpolluted	1.037	**Moderated polluted**
G. Avg.	-1.109	Unpolluted	-0.714	Unpolluted	-0.657	Unpolluted	0.203	Unpolluted to moderated	-0.080	Unpolluted	0.965	Unpolluted to moderated
Sites	Al		Cr		Mn		Al		Cr		Mn	
	Er	Risk grade	Er	Risk grade	Er	Risk grade	Er	Risk grade	Er	Risk grade	Er	Risk grade
Site 1	–	–	2.341	Low risk	1.049	Low risk	–	–	3.633	Low risk	3.230	Low risk
Site 2	–	–	1.757	Low risk	0.878	Low risk	–	–	2.726	Low risk	2.703	Low risk
Site 3	–	–	1.649	Low risk	1.043	Low risk	–	–	2.558	Low risk	3.212	Low risk
G. Avg.	–	–	1.927	Low risk	0.987	Low risk	–	–	2.990	Low risk	3.041	Low risk
Sites	DC		PLI		RI		DC		PLI		RI	
	value	Grade	value	Grade	value	Grade	value	Grade	value	Grade	value	Grade
Site 1	3.057	Low	1.006	Polluted	3.390	Low risk	7.127	Low degree of contamination	2.294	**Polluted**	6.862	Low ecological risk
Site 2	2.394	Low	0.783	Unpolluted	2.634	Low risk	5.650	Low degree of contamination	1.786	**Polluted**	5.429	Low ecological risk
Site 3	2.533	Low	0.821	Unpolluted	2.691	Low risk	6.144	Low degree of contamination	1.873	**Polluted**	5.770	Low ecological risk
G. Avg.	2.667	Low	0.872	Unpolluted	2.914	Low risk	6.314	Low degree of contamination	1.989	**Polluted**	6.031	Low ecological risk

ASV = Average shale values. PAHDC = Pre-Aswan High Dam Concentrations. G. Avg. = grand average.

Table (7): Results of the single and integrated pollution indices of the measured HMs in BSC sediment during different seasons.

	According to ASV **(Turekian and Wedepohl, 1961)**						According to PAHDC of the River Nile sediments **(Abu Khatita, 2011)**					
Seasons	Al		Cr		Mn		Al		Cr		Mn	
	EF	Rank	EF	Rank	EF	Rank	EF	Rank	EF	Rank	EF	Rank
Spring	1.000	No enrichment	1.644	Minor	1.569	Minor	1.000	No enrichment	1.027	Minor	1.945	Minor
Summer	1.000	No enrichment	0.866	Minor	1.009	Minor	1.000	No enrichment	0.541	No enrichment	1.252	Minor
Autumn	1.000	No enrichment	1.405	Minor	1.459	Minor	1.000	No enrichment	0.877	No enrichment	1.809	Minor
Winter	1.000	No enrichment	1.384	Minor	1.467	Minor	1.000	No enrichment	0.865	No enrichment	1.819	Minor
G. Avg.	1.000	No enrichment	1.350		1.412		1.000	No enrichment	0.843	No enrichment	1.751	Minor
Seasons	Al		Cr		Mn		Al		Cr		Mn	
	CF	Rank	CF	Rank	CF	Rank	CF	Rank	CF	Rank	CF	Rank
Spring	0.595	Low	0.958	Low	0.849	Low	1.479	**Moderate**	1.487	**Moderate**	2.616	**Moderate**
Summer	0.756	Low	0.697	Low	0.779	Low	1.877	**Moderate**	1.082	**Moderate**	2.398	**Moderate**
Autumn	0.721	Low	1.002	**Moderate**	1.028	**Moderate**	1.790	**Moderate**	1.555	**Moderate**	3.167	**Considerable**
Winter	0.727	Low	1.021	**Moderate**	1.056	**Moderate**	1.805	**Moderate**	1.585	**Moderate**	3.252	**Considerable**
G. Avg.	0.716	Low	0.964	Low	0.987	Low	1.778	**Moderate**	1.495	**Moderate**	3.041	**Considerable**
Seasons	Al		Cr		Mn		Al		Cr		Mn	
	Cp	Pollution	Cp	Pollution	Cp	Pollution	Cp	Pollution	Cp	Pollution	Cp	Pollution
Spring	0.789	Low	1.200	**Moderate**	0.859	Low	1.959	**Moderate**	1.862	**Moderate**	2.645	**Moderate**
Summer	1.031	**Moderate**	1.154	**Moderate**	1.255	**Moderate**	2.561	**Moderate**	1.793	**Moderate**	3.866	**Severe or very severe**
Autumn	0.960	Low	1.404	**Moderate**	1.439	**Moderate**	2.385	**Moderate**	2.172	**Moderate**	4.431	**Severe or very severe**
Winter	0.894	Low	1.456	**Moderate**	1.345	**Moderate**	2.220	**Moderate**	2.259	**Moderate**	4.141	**Severe or very severe**
G. Avg.	1.031	**Moderate**	1.456	**Moderate**	1.439	**Moderate**	2.244	**Moderate**	2.109	**Moderate**	4.079	**Severe or very severe**
Seasons	Al		Cr		Mn		Al		Cr		Mn	

	Igeo	Rank	*Igeo*	Rank	*Igeo*	Rank	*Igeo*	Rank	*Igeo*	Rank	*Igeo*	Rank
Spring	-1.402	Unpolluted	-0.688	Unpolluted	-0.821	Unpolluted	-0.089	Unpolluted	-0.054	Unpolluted	0.802	Unpolluted to moderated
Summer	-1.095	Unpolluted	-1.335	Unpolluted	-1.101	Unpolluted	0.218	Unpolluted to moderated	-0.701	Unpolluted	0.521	Unpolluted to moderated
Autumn	-1.084	Unpolluted	-0.614	Unpolluted	-0.573	Unpolluted	0.229	Unpolluted to moderated	0.020	Unpolluted to moderated	1.049	**Moderated polluted**
Winter	-1.070	Unpolluted	-0.614	Unpolluted	-0.549	Unpolluted	0.242	Unpolluted to moderated	0.020	Unpolluted to moderated	1.073	**Moderated polluted**
G. Avg.	-1.109	Unpolluted	-0.714	Unpolluted	-0.657	Unpolluted	0.203	Unpolluted to moderated	-0.080	Unpolluted	0.965	Unpolluted to moderated
Seasons	Al		Cr		Mn		Al		Cr		Mn	
	Er	Risk grade	Er	Risk grade	Er	Risk grade	Er	Risk grade	Er	Risk grade	Er	Risk grade
Spring	–	–	1.916	Low risk	0.849	Low risk	–	–	2.974	Low risk	2.616	Low risk
Summer	–	–	1.394	Low risk	0.779	Low risk	–	–	2.163	Low risk	2.398	Low risk
Autumn	–	–	2.005	Low risk	1.028	Low risk	–	–	3.110	Low risk	3.167	Low risk
Winter	–	–	2.042	Low risk	1.056	Low risk	–	–	3.169	Low risk	3.252	Low risk
G. Avg.	–	–	1.927	Low risk	0.987	Low risk	–	–	2.990	Low risk	3.041	Low risk
Seasons	DC		PLI		RI		DC		PLI		RI	
	value	Grade	value	Grade	value	Grade	value	Grade	value	Grade	value	Grade
Spring	2.403	Low	0.779	Unpolluted	2.766	Low risk	5.582	Low degree of contamination	1.776	**Polluted**	5.590	Low ecological risk
Summer	2.231	Low	0.739	Unpolluted	2.173	Low risk	5.356	Low degree of contamination	1.686	**Polluted**	4.561	Low ecological risk
Autumn	2.751	Low	0.900	Unpolluted	3.033	Low risk	6.512	Low degree of contamination	2.052	**Polluted**	6.277	Low ecological risk
Winter	2.804	Low	0.915	Unpolluted	3.098	Low risk	6.641	Low degree of contamination	2.086	**Polluted**	6.421	Low ecological risk
G. Avg.	2.667	Low	0.872	Unpolluted	2.914	Low risk	6.314	Low degree of contamination	1.989	**Polluted**	6.031	Low ecological risk

ASV = Average shale values. PAHDC = Pre-Aswan High Dam Concentrations. G. Avg. = grand average.

Table (8): Spatial and seasonal calculated CDI (mg/kg/day), HQ, HI and CRI values of metals from dermal contact in sediment of BSC.

	Metals					
	Aluminium (Al)		Chromium (Cr)		Manganese (Mn)	
	Adult	Children	Adult	Children	Adult	Children
CDI						
Sites						
Site 1	4.27E-02	1.37E-03	6.72E-05	2.16E-06	5.68E-04	1.82E-05
Site 2	3.25E-02	1.04E-03	5.04E-05	1.62E-06	4.76E-04	1.53E-05
Site 3	3.40E-02	1.09E-03	4.73E-05	1.52E-06	5.65E-04	1.81E-05
G. Avg.	3.65E-02	1.17E-03	5.53E-05	1.77E-06	5.35E-04	1.72E-05
Seasons						
Spring	3.04E-02	9.75E-04	5.50E-05	1.76E-06	4.60E-04	1.48E-05
Summer	3.85E-02	1.24E-03	4.00E-05	1.28E-06	4.22E-04	1.35E-05
Autumn	3.68E-02	1.18E-03	5.75E-05	1.85E-06	5.57E-04	1.79E-05
Winter	3.71E-02	1.19E-03	5.86E-05	1.88E-06	5.72E-04	1.84E-05
G. Avg.	3.65E-02	1.17E-03	5.53E-05	1.77E-06	5.35E-04	1.72E-05
RfD_{derm}	1.00E-01		6.00E-05		1.84E-03	
HQ						
Sites						
Site 1	4.27E-01	1.37E-02	1.12E+00	3.59E-02	3.09E-01	9.91E-03
Site 2	3.25E-01	1.04E-02	8.40E-01	2.70E-02	2.59E-01	8.29E-03
Site 3	3.40E-01	1.09E-02	7.88E-01	2.53E-02	3.07E-01	9.85E-03
G. Avg.	3.65E-01	1.17E-02	9.22E-01	2.96E-02	2.91E-01	9.33E-03
Seasons						
Spring	3.04E-01	9.75E-03	9.17E-01	2.94E-02	2.50E-01	8.03E-03
Summer	3.85E-01	1.24E-02	6.67E-01	2.14E-02	2.29E-01	7.36E-03
Autumn	3.68E-01	1.18E-02	9.59E-01	3.08E-02	3.03E-01	9.72E-03
Winter	3.71E-01	1.19E-02	9.77E-01	3.13E-02	3.11E-01	9.98E-03
G. Avg.	3.65E-01	1.17E-02	9.22E-01	2.96E-02	2.91E-01	9.33E-03
HI						
Sites	**Adult**	**children**	**Seasons**	**Adult**	**children**	
Site 1	1.86E+00	5.95E-02	Spring	1.47E+00	4.72E-02	
Site 2	1.42E+00	4.57E-02	Summer	1.28E+00	4.11E-02	
Site 3	1.44E+00	4.60E-02	Autumn	1.63E+00	5.23E-02	
G. Avg.	1.58E+00	5.06E-02	Winter	1.66E+00	5.32E-02	
			G. Avg.	1.58E+00	5.06E-02	
CRI of Cr						
Sites	**Adult**	**children**	**Seasons**	**Adult**	**children**	
Site 1	2.82E-03	9.05E-05	Spring	2.31E-03	7.41E-05	
Site 2	2.12E-03	6.79E-05	Summer	1.68E-03	5.39E-05	
Site 3	1.99E-03	6.37E-05	Autumn	2.42E-03	7.75E-05	
G. Avg.	2.32E-03	7.45E-05	Winter	2.46E-03	7.90E-05	
			G. Avg.	2.32E-03	7.45E-05	

CDI = chronic daily intake. HQ = hazard quotient. HI = hazard index.
CRI = Carcinogenic risk index. G. Avg. = grand average.
RfD_{derm} = Dermal RfD (mg/kg/day).

HI can serve as a conservative evaluation tool to estimate high-end-risk rather than low-end risk to protect the public **(Qu *et al.*, 2012)**. **Paustenbach (2003)** and **Qing *et al.* (2015)** reported that the chronic non-cancer effect is possible to happen and the possibility increases with the HI values increase, if the HI > 1, whereas, if the value of HI < 1, so, no risk of non-carcinogenic effects is believed to occur. By comparing the children's and adult's HI values, it can be deduced that adults have much more chances of non-carcinogenic risk from Cr in the sediment than children. Carcinogenic risk is considered as the possibility of an individual evolving any kind of cancer in the entire life span as a result of exposure to carcinogenic risks **(Li *et al.*, 2014)**. The carcinogenic risk index (CRI) for dermal contact of exposure; of adults and children; was computed for Cr (Table 8). The CRI from Cr at all sites and during different seasons via dermal contact were higher than the target value 1×10^{-6} **(USEPA, 2011)**, i.e., were so much higher than the standard value that there could be cancer risk to adult and children in the investigated area. It was reported previously that the chromium, especially Cr (VI), has been determined to be a human carcinogen for which there is adequate evidence of carcinogenic risk **(Wang *et al.*, 2011; Karimi Nezhad *et al.*, 2015)**.

CONCLUSION

The present work has shown the presence of higher Al, Cr, and Mn concentrations in the BSC sediments, which are obvious anthropogenic activities influences sign within the BSC aquatic environment. Values of the sediment pollution indices may suggest that sediments of BSC are categorized as unpolluted to low/or moderately polluted. Comparing the HMs concentrations in the sediment of BSC with the SQGs and sediment classification grades indicate that there are levels with the potential to impact the ecosystem. Human health risk assessment indices were used to evaluate exposure to HMs from dermal sediments exposure. There is no non-carcinogenic and carcinogenic serious risk for children right now as their health risk indices values are lower than the safe threshold levels. For an adult, the Cr carcinogenic risk value is higher than the threshold value (1×10^{-6}), indicating that adults are facing Cr threat. Finally, it is recommended to prohibit the discharges of agricultural runoffs, industrial wastes, and untreated urban and other wastes into the BSC. The present work can help decision-makers with an insightful view on improving the environmental protection strategies of BSC.

Funding

This research (2014 – 2016) was funded by the University of Minoufiya Research Projects Fund for this article's first author.

REFERENCES

Abdel-Satar, A.M. (2005). Quality of River Nile sediments from Idfo to Cairo. Egyptian Journal of Aquatic Research, 31(2): 182–199. http://www.niof.sci.eg/images/ejar/vol-31/n2/QUALITY%20OF%20RIVER%20NILE%20SEDIMENTS%20FROM%20IDFO%20TO.pdf

Abu Khatita, A.M. (2011). Assessment of soil and sediment contamination in the Middle Nile Delta area (Egypt)- Geo-Environmental study using combined sedimentological, geophysical and geochemical methods. Faculty of Science, Friedrich-Alexander University, Erlangen-Nürnberg, Germany, 214 p. https://opus4.kobv.de/opus4-fau/frontdoor/index/index/docId/1884

Al-Alimi, A.K.A.A. and Alhudify, N.S. (2016). Assessment of heavy metals contamination and its ecological risk in the surface sediments of al-mukalla coast, Yemen. Journal of Scientific and Engineering Research, 3(3): 13–23. http://jsaer.com/download/vol-3-iss-3-2016/JSAER2016-03-03-13-23.pdf

Al-Taani, A.A.; Rashdan, M. and Khashashneh, S. (2015). Atmospheric dry deposition of mineral dust to the Gulf of Aqaba, Red Sea: Rate and trace elements. Marine Pollution Bulletin, 92(1): 252–258. https://doi.org/10.1016/j.marpolbul.2014.11.047

Ali, M.M.; Ali, M.L.; Islam, M.S. and Rahman, M.Z. (2016). Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh. Environmental Nanotechnology, Monitoring & Management, 5: 27–35. https://doi.org/10.1016/ j.enmm.2016.01.002

Alnenaei, A.E. and Authman, M. (2010). Impact of human activities on aluminum contamination in the drainage canals in the Nile Delta, Egypt. Toxicology Letters, 196S: S114, P108-002. https://doi.org/10.1016/j.toxlet.2010.03.403

Anonymous (1997). Investigation of Lake Qarun ecosystem, Final Report submitted to USAID and National Institute of Oceanography and Fisheries (NIOF), Cairo, Egypt, 287 p.

ATSDR (2012). Toxicological profile for manganese. Agency for Toxic Substances and Disease Registry, U.S. Department of Health and Human Services, Public Health Service, Atlanta, GA, 556 p. https://www.atsdr.cdc.gov/ToxProfiles/tp.asp?id=102&tid=23

Authman, M.M.N. (2008). *Oreochromis niloticus* as a biomonitor of heavy metal pollution with emphasis on potential risk and relation to some biological aspects. Global Veterenaria, 2(3): 104–109. http://idosi.org/gv/gv2(3)08/3.pdf

Authman, M.M.N. (2011). Environmental and experimental studies of aluminium toxicity on the liver of *Oreochromis niloticus* (Linnaeus, 1758) fish. Life Science Journal, 8(4): 764–776. http://www.lifesciencesite.com/lsj/life0804/100_7479life0804_764_776.pdf

Authman, M.M.N.; Bayoumy, E.M. and Kenawy, A.M. (2008). Heavy metal concentrations and liver histopathology of *Oreochromis niloticus* in relation to aquatic pollution. Global Veterenaria, 2(3): 110–116. http://idosi.org/gv/gv2(3)08/4.pdf

Bai, J.; Cui, B.; Chen, B.; Zhang, K.; Deng, W.; Gao, H. and Xiao, R. (2011). Spatial distribution and ecological risk assessment of heavy metals in surface sediments from a typical plateau lake wetland, China. Ecological Modelling, 222(2): 301–306. https://doi.org/10.1016/j.ecolmodel.2009.12.002

Barik, S.K.; Muduli, P.R.; Mohanty, B.; Rath, P. and Samanta, S. (2018). Spatial distribution and potential biological risk of some metals in relation to granulometric content in core sediments from Chilika Lake, India. Environmental Science and Pollution Research, 25(1): 572–587. https://doi.org/10.1007/s11356-017-0421-4

Bastami, K.D.; Afkhami, M.; Mohammadizadeh, M.; Ehsanpour, M.; Chambari, S.; Aghaei, S.; Esmaeilzadeh, M.; Neyestani, M.R.; Lagzaee, F. and Baniamam, M. (2015). Bioaccumulation and ecological risk assessment of heavy metals in the sediments and mullet *Liza klunzingeri* in the northern part of the Persian Gulf. Marine Pollution Bulletin, 94(1-2): 329–334. https://doi.org/10.1016/j.marpolbul.2015.01.019

Batayneh, A.T.; Ghrefat, H.; Zumlot, T.; Elawadi, E.; Mogren, S.; Zaman, H.; Al-Taani, A.A.; Nazzal, Y. and Elwahaidi, M. (2015). Assessing of metals and metalloids in surface sediments along the Gulf of Aqaba Coast, Northwestern Saudi Arabia. Journal of Coastal Research, 31(1): 163–176. https://doi.org/10.2112/JCOASTRES-D-13-00143.1

Bibi, M.; Wagreich, M. and Iqbal, S. (2020). Trace metals as markers for historical anthropogenic contamination: Evidence from the Peshawar Basin, Pakistan. Science of the Total Environment, 703: 134926. https://doi.org/10.1016/j.scitotenv.2019.134926

Bing, H.; Wu, Y.; Zhou, J.; Sun, H.; Wang, X. and Zhu, H. (2019). Spatial variation of heavy metal contamination in the riparian sediments after two-year flow regulation in the Three Gorges Reservoir, China. Science of The total Environment, 649: 1004–1016. https://doi.org/10.1016/j.scitotenv.2018.08.401

Binning, K. and Baird, D. (2001). Survey of heavy metals in the sediments of the Swartkops River Estuary, Port Elizabeth South Africa. Water SA, 27(4): 461–466. http://dx.doi.org/10.4314/wsa.v27i4.4958

Black, M.C. and Williams, P.L. (2001). Preliminary assessment of metal toxicity in the middle tisza river (Hungary) flood plain. Journal of Soils and Sediments, 1(4): 213–216. https://doi.org/10.1007/BF02987727

Buhari, T.R.I. and Ismail, A. (2016). Heavy Metals Pollution and Ecological Risk Assessment in Surface Sediments of West Coast of Peninsular Malaysia. International Journal of Environmental Science and Development, 7(10): 750–756. https://doi:10.18178/ijesd.2016.7.10.874

CCME (2012). Canadian Sediment Quality Guidelines for the Protection of Aquatic Life. Canadian Council of Ministers of the Environment, December 2012, 9 p. http://probeinternational.org/library/wp-content/uploads/2013/03/CCME-Sediment-Quality-Guidelines-for-the-Protection-of-Aquatic-Life-Dec-2012.pdf

Chabukdhara, M. and Nema, A.K. (2013). Heavy metals assessment in urban soil around industrial clusters in Ghaziabad, India: Probabilistic health risk approach. Ecotoxicology and Environmental Safety, 87: 57–64. https://doi.org/10.1016/j.ecoenv.2012.08.032

Dauvalter, V. and Rognerud, S. (2001). Heavy metal pollution in sediments of the Pasvik River drainage. Chemosphere, 42(1): 9–18. https://doi.org/10.1016/S0045-6535(00)00094-1

Davies, C.a.L.; Tomlinson, K. and Stephenson, T. (1991). Heavy metals in river tees estuary sediments. Environmental Technology, 12(11): 961–972. https://doi.org/10.1080/09593339109385095

de Mora, S.; Fowler, S.W.; Wyse, E. and Azemard, S. (2004). Distribution of heavy metals in marine bivalves, fish and coastal sediments in the Gulf and Gulf of Oman. Marine Pollution Bulletin, 49(5): 410–424. https://doi.org/10.1016/j.marpolbul.2004.02.029

Duncan, D.B. (1955). Multiple Range and Multiple *F* Tests. Biometrics, 11(1): 1-42. https://doi:10.2307/3001478

El-Gamal, A.A. (2016). Sediment and Water Quality of the Nile Delta Estuaries. In: "The Nile Delta. The Handbook of Environmental Chemistry", vol 55. Negm, A.M. (Ed.). Springer International Publishing, Cham, Switzerland, pp. 347–378 https://doi.org/10.1007/698_2016_47

El-Radaideh, N.; Al-Taani, A.A. and Al Khateeb, W.M. (2017). Characteristics and quality of reservoir sediments, Mujib Dam, Central Jordan, as a case study. Environmental Monitoring and Assessment, 189(4): 143, 118 p. https://doi.org/10.1007/s10661-017-5836-3

El-Sayed, S.A.; Moussa, E.M.M. and El-Sabagh, M.E.I. (2015). Evaluation of heavy metal content in Qaroun Lake, El-Fayoum, Egypt. Part I: Bottom sediments. Journal of Radiation Research and Applied Sciences, 8(3): 276–285. https://doi.org/10.1016/j.jrras.2015.02.011

El Bouraie, M.M.; El Barbary, A.A.; Yehia, M.M. and Motawea, E.A. (2010). Heavy metal concentrations in surface river water and bed sediments at Nile Delta in Egypt. Suoseura - Finnish Peatland Society, 61(1): 1–12. http://www.suoseura.fi/suo

Elewa, A.S. (1993). Distribution of Mn, Cu, Zn, and Cd in water, sediments and aquatic plants in River Nile and Aswan Reservoir. Egyptian Journal of Applied Science, 8(2): 711–723.

Elkady, A.A.; Sweet, S.T.; Wade, T.L. and Klein, A.G. (2015). Distribution and assessment of heavy metals in the aquatic environment of Lake Manzala, Egypt. Ecological Indicators, 58: 445–457. https://doi.org/10.1016/j.ecolind.2015.05.029

Gao, X. and Chen, C.-T.A. (2012). Heavy metal pollution status in surface sediments of the coastal Bohai Bay. Water Research, 46(6): 1901–1911. https://doi.org/10.1016/j.watres.2012.01.007

Gerke, T.L. and Little, B.J. (2018). Manganese. In: "Encyclopedia of Geochemistry: A Comprehensive Reference Source on the Chemistry of the Earth". White, W.M. (Ed.). Springer International Publishing, Cham, Switzerland: pp. 864–867. https://doi.org/10.1007/978-3-319-39312-4_119

Giesy, J.P. and Hoke, R.A. (1990). Freshwater Sediment Quality Criteria: Toxicity Bioassessment. In: "Sediments: Chemistry and Toxicity of In-Place Pollutants". Baudo, R.; Giesy, J.P. & Muntau, H. (Eds.). Lewis Publishers Inc., Ann Arbor, MI, pp. 265–348 http://www.usask.ca/toxicology/jgiesy/pdf/publications/BC-029.pdf

Goher, M.E.; Ali, M.H.H. and El-Sayed, S.M. (2019). Heavy metals contents in Nasser Lake and the Nile River, Egypt: An overview. Egyptian Journal of Aquatic Research, https://doi.org/10.1016/j.ejar.2019.12.002

Goher, M.E.; Farhat, H.I.; Abdo, M.H. and Salem, S.G. (2014). Metal pollution assessment in the surface sediment of Lake Nasser, Egypt. Egyptian Journal of Aquatic Research, 40(3): 213–224. https://doi.org/10.1016/j.ejar.2014.09.004

Gu, J.; Salem, A. and Chen, Z. (2013). Lagoons of the Nile delta, Egypt, heavy metal sink: With a special reference to the Yangtze estuary of China. Estuarine, Coastal and Shelf Science, 117: 282–292. https://doi.org/10.1016/j.ecss.2012.06.012

Hakanson, L. (1980). An ecological risk index for aquatic pollution control. A sedimentological approach. Water Research, 14(8): 975–1001. https://doi.org/10.1016/0043-1354(80)90143-8

Harikumar, P.S. and Jisha, T.S. (2010). Distribution pattern of trace metal pollutants in the sediments of an urban wetland in the southwest coast of India. International Journal of

Engineering Science and Technology, 2(5): 840–850. https://www.ijest.info/docs/IJEST10-02-05-40.pdf

Ho, K.C. and Hui, K.C.C. (2001). Chemical contamination of the East River (Dongjiang) and its implication on sustainable development in the Pearl River Delta. Environment International, 26(5): 303–308. https://doi.org/10.1016/S0160-4120(01)00004-6

Huang, B.; Guo, Z.; Xiao, X.; Zeng, P. and Peng, C. (2019). Changes in chemical fractions and ecological risk prediction of heavy metals in estuarine sediments of Chunfeng Lake estuary, China. Marine Pollution Bulletin, 138: 575–583. https://doi.org/10.1016/j.marpolbul.2018.12.015

Huang, P.; Li, T.-G.; Li, A.-C.; Yu, X.-K. and Hu, N.-J. (2014). Distribution, enrichment and sources of heavy metals in surface sediments of the North Yellow Sea. Continental Shelf Research, 73: 1–13. https://doi.org/10.1016/j.csr.2013.11.014

Iqbal, J.; Saleem, M. and Shah, M.H. (2016). Spatial distribution, environmental assessment and source identification of metals content in surface sediments of freshwater reservoir, Pakistan. Chemie der Erde, 76(1): 171–177. https://doi.org/10.1016/j.chemer.2016.02.002

Islam, M.S.; Ahmed, M.K.; Raknuzzaman, M.; Habibullah-Al-Mamun, M. and Islam, M.K. (2015). Heavy metal pollution in surface water and sediment: A preliminary assessment of an urban river in a developing country. Ecological Indicators, 48: 282–291. https://doi.org/10.1016/j.ecolind.2014.08.016

Islam, M.S.; Han, S.; Ahmed, M.K. and Masunaga, S. (2014). Assessment of Trace Metal Contamination in Water and Sediment of Some Rivers in Bangladesh. Journal of Water and Environment Technology, 12(2): 109–121. https://doi.org/10.2965/jwet.2014.109

Jones, D.S.; Suter Ii, G.W. and Hull, R.N. (1997). Toxicological benchmarks for screening contaminants of potential concern for effects on sediment-associated biota: 1997 Revision. ES/ER/TM-95/R4, Prepared for the U.S. Department of Energy under Contract DE-AC05-84OR21400 by Lockheed Martin Energy Systems, INC., Oak Ridge, TN, 48 p. https://rais.ornl.gov/documents/tm95r4.pdf

Karimi Nezhad, M.T.; Tabatabaii, S.M. and Gholami, A. (2015). Geochemical assessment of steel smelter-impacted urban soils, Ahvaz, Iran. Journal of Geochemical Exploration, 152: 91–109. https://doi.org/10.1016/j.gexplo.2015.02.005

Karthikeyan, R.; Vijayalakshmi, S. and Balasubramanian, T. (2007). Monthly Variation of Heavy Metal and Metal Resistant Bacteria from Uppanar Estuary (South East Coast of India). Research Journal of Microbiology, 2(1): 50–57. https://doi.org/10.3923/jm.2007.50.57

Khallaf, E.A. (2002). An ecological assessment of Bahr Shebeen Nilotic Canal (A Review Paper). Journal of Union of Arab Biologists (Zoology), Cairo, 17(A): 65–75.

Khallaf, E.A.; Authman, M.M.N. and Alne-na-ei, A.A. (2018a). Contamination and Ecological Hazard Assessment of Heavy Metals in Freshwater Sediments and *Oreochromis niloticus* (Linnaeus, 1758) Fish Muscles in a Nile River Canal in Egypt. Environmental Science and Pollution Research, 25(14): 13796–13812. https://doi.org/10.1007/s11356-018-1521-5

Khallaf, E.A.; Authman, M.M.N. and Alne-na-ei, A.A. (2018b). Evaluation of organochlorine and organophosphorus pesticides residues in the sediment and muscles of Nile tilapia

Oreochromis niloticus (Linnaeus, 1758) fish from a River Nile Canal, Egypt. International Journal of Environmental Studies, 75(3): 443–465. https://doi.org/10.1080/00207233.2017.1378019

Khallaf, E.A. and Authman, M.N. (1992). Changes in diet, prey size and feeding habit in *Bagrus bayad*, and possible interactions with *B. docmac* in a Nile canal. Environmental Biology of Fishes, 34(4): 425–431. https://doi.org/10.1007/bf00004747

Khan, A.G.; Kuek, C.; Chaudhry, T.M.; Khoo, C.S. and Hayes, W.J. (2000). Role of plants, mycorrhizae and phytochelators in heavy metal contaminated land remediation. Chemosphere, 41(1): 197–207. https://doi.org/10.1016/S0045-6535(99)00412-9

Korium, M.A.; Toufeek, M.E.F. and El-Haty, E.Y. (2006). Distribution of Al, Ag, Cr, Mn, Ni, Zn and some physicochemical characteristics of River Nile water and sediment at Aswan. Egyptian Journal of Aquatic Research, 32(2): 208–225. http://www.niof.sci.eg/images/ejar/vol-32/n2/DISTRIBUTION%20OF%20AL,%20AG,%20CR,%20MN, %20NI, %20ZN%20AND%20SOME.pdf

Kouadio, I. and Trefry, J.H. (1987). Sediment trace metal contamination in the Ivory Coast, West Africa. Water, Air, and Soil Pollution, 32(1): 145–154. https://doi.org/10.1007/BF00227690

Lakshmanasenthil, S.; Vinothkumar, T.; Ajithkumar, T.T.; Marudhupandi, T.; Veettil, D.K.; Ganeshamurthy, R.; Ghosh, S. and Balasubramanian, T. (2013). Harmful metals concentration in sediments and fishes of biologically important estuary, Bay of Bengal. Journal of Environmental Health Sciences & Engineering, 11(1): 33, 37 p. https://doi.org/10.1186/2052-336X-11-33

Lasheen, M.R. and Ammar, N.S. (2009). Speciation of some heavy metals in River Nile sediments, Cairo, Egypt. Environmentalist, 29(1): 8–16. https://doi.org/10.1007/s10669-008-9175-3

Li, Z.; Ma, Z.; Van Der Kuijp, T.J.; Yuan, Z. and Huang, L. (2014). A review of soil heavy metal pollution from mines in China: Pollution and health risk assessment. Science of the Total Environment, 468–469: 843–853. https://doi.org/10.1016/j.scitotenv.2013.08.090

Lin, L.; Li, C.; Yang, W.; Zhao, L.; Liu, M.; Li, Q. and Crittenden, J.C. (2020). Spatial variations and periodic changes in heavy metals in surface water and sediments of the Three Gorges Reservoir, China. Chemosphere, 240: 124837. https://doi.org/10.1016/j.chemosphere.2019.124837

Long, E.R.; Macdonald, D.D.; Smith, S.L. and Calder, F.D. (1995). Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environmental Management, 19(1): 81–97. https://doi.org/10.1007/BF02472006

Loska, K. and Wiechuła, D. (2003). Application of principal component analysis for the estimation of source of heavy metal contamination in surface sediments from the Rybnik Reservoir. Chemosphere, 51(8): 723–733. https://doi.org/10.1016/S0045-6535(03)00187-5

Maanan, M.; Saddik, M.; Maanan, M.; Chaibi, M.; Assobhei, O. and Zourarah, B. (2015). Environmental and ecological risk assessment of heavy metals in sediments of Nador lagoon, Morocco. Ecological Indicators, 48: 616–626. https://doi.org/10.1016/ j.ecolind.2014.09.034

Macdonald, D.D.; Carr, R.S.; Calder, F.D.; Long, E.R. and Ingersoll, C.G. (1996). Development and evaluation of sediment quality guidelines for Florida coastal waters. Ecotoxicology, 5(4): 253–278. https://doi.org/10.1007/bf00118995

MacDonald, D.D.; Ingersoll, C.G. and Berger, T.A. (2000). Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems. Archives of Environmental Contamination and Toxicology, 39(1): 20–31. https://doi.org/10.1007/s002440010075

Mahmoud, H.M.; Nassar, H.F.; Hamouda, A.S. and Mabrook, F. (2017). Ecological Risk Assessment of Metals Contaminated Sediments from the Nile River at Beni-Suef Governorate, Egypt. Journal of Applied Life Sciences International, 14(1): 1–11. https://doi.org/10.9734/JALSI/2017/36288

Manoj, K. and Padhy, P.K. (2014). Distribution, enrichment and ecological risk assessment of six elements in bed sediments of a tropical river, Chottanagpur Plateau: A spatial and temporal appraisal. Journal of Environmental Protection, 5(14): 1419–1434. https://doi.org/10.4236/jep.2014.514136

Mekkawy, I.A.A.; Mahmoud, U.M. and Ibrahim, A.T.A. (2008). Heavy metal distribution in some organs of *Oreochromis niloticus* (Linnaeus, 1758) collected from three localities at Assiut, Egypt and the corresponding tissue damage. Journal of the Egyptian German Society of Zoology, 55(B): 97–127.

Mohiuddin, K.M.; Ogawa, Y.; Zakir, H.M.; Otomo, K. and Shikazono, N. (2011). Heavy metals contamination in water and sediments of an urban river in a developing country. International Journal of Environmental Science & Technology, 8(4): 723–736. https://doi.org/10.1007/BF03326257

Mohiuddin, K.M.; Zakir, H.M.; Otomo, K.; Sharmin, S. and Shikazono, N. (2010). Geochemical distribution of trace metal pollutants in water and sediments of downstream of an urban river. International Journal of Environmental Science & Technology, 7(1): 17–28. https://doi.org/10.1007/BF03326113

Mookherjee, M. (2018). Aluminum. In: "Encyclopedia of Geochemistry: A Comprehensive Reference Source on the Chemistry of the Earth". White, W.M. (Ed.). Springer International Publishing, Cham, Switzerland: pp. 27–29. https://doi.org/10.1007/978-3-319-39312-4_214

Müller, G. (1969). Index of geo-accumulation in sediments of the Rhine River. Geojournal, 2(3): 108–118.

Muohi, A.W.; Onyari, J.M.; Omondi, J.G. and Mavuti, K.M. (2003). Heavy metals in sediments from Makupa and Port–Reitz Creek systems: Kenyan Coast. Environment International, 28(7): 639–647. https://doi.org/10.1016/S0160-4120(02)00104-6

Osman, A.G.M.; Abuel-Fadl, K.Y.; Elbtar, A.M. and Taha, M.a.M. (2012). Seasonal variations of some heavy metals in water, sediments and fish samples collected from the River Nile, Egypt. Environmental Research Journal, 6(5): 321–328. https://doi.org/10.3923/erj.2012.321.328

Osman, A.G.M. and Kloas, W. (2010). Water quality and heavy metal monitoring in water, sediments, and tissues of the African Catfish *Clarias gariepinus* (Burchell, 1822) from the River Nile, Egypt. Journal of Environmental Protection, 1(4): 389–400. https://doi.org/10.4236/jep.2010.14045

Osman, G.Y.; Radwan, N.A.; Khalil, A.I. and Abo Msalam, A.M. (2008). Helminth communities of *Bagrus docmac* and *Malepterurus electricus* in three water bodies at Menoufiya Governorate, Egypt. Egyptian Journal of Experimental Biology (Zoology), 4(0): 177–192. http://www.egyseb.net/ejebz/?mno=188917

Oyewumi, O.; Feldman, J. and Gourley, J.R. (2017). Evaluating stream sediment chemistry within an agricultural catchment of Lebanon, Northeastern USA. Environmental Monitoring and Assessment, 189: 141, 115 p. https://doi.org/10.1007/s10661-017-5856-z

Palma, P.; Ledo, L. and Alvarenga, P. (2015). Assessment of trace element pollution and its environmental risk to freshwater sediments influenced by anthropogenic contributions: The case study of Alqueva reservoir (Guadiana Basin). CATENA, 128: 174–184. https://doi.org/10.1016/j.catena.2015.02.002

Paustenbach, D.J. (2003). Human and Ecological Risk Assessment: Theory and Practice. Human and Ecological Risk Assessment, 9(4): 1089–1090. https://doi.org/10.1080/713610025

Pekey, H.; Karakaş, D.; Ayberk, S.; Tolun, L. and Bakoğlu, M. (2004). Ecological risk assessment using trace elements from surface sediments of İzmit Bay (Northeastern Marmara Sea) Turkey. Marine Pollution Bulletin, 48(9): 946–953. https://doi.org/10.1016/j.marpolbul.2003.11.023

Peng, J.-F.; Song, Y.-H.; Yuan, P.; Cui, X.-Y. and Qiu, G.-L. (2009). The remediation of heavy metals contaminated sediment. Journal of Hazardous Materials, 161(2-3): 633–640. https://doi.org/10.1016/j.jhazmat.2008.04.061

Persaud, D.; Jaagumagi, R. and Hayton, A. (1993). Guidelines for the protection and management of aquatic sediment quality in Ontario. Ontario Ministry of Environment and Energy, Ontario, Canada, 39p http://www.itrcweb.org/contseds-bioavailability/References/guide_aquatic_sed93.pdf

Proshad, R.; Islam, M.S.; Kormoker, T.; Masud, M.E.M. and Ali, M.M. (2018). Assessment of toxic metals contamination with ecological risk of surface water and sediment of Korotoa River in Bangladesh. International Journal of Advanced Geosciences, 6(2): 214–221. https://doi.org/10.14419/ijag.v6i2.13742

Proshad, R.; Kormoker, T. and Islam, S. (2019). Distribution, source identification, ecological and health risks of heavy metals in surface sediments of the Rupsa River, Bangladesh. Toxin Reviews: 1–26. https://doi.org/10.1080/15569543.2018.1564143

Qi, W.; Liu, H.; Han, H.; Chai, W. and Qu, J. (2013). A study of metal contamination in sediments in Beisan River System. Acta Scientiae Circumstantiae, 33(1): 117–124. http://caod.oriprobe.com/articles/31317602/A_study_of_metal_contamination_in_sediments_in_Beisan_River_System.htm

Qing, X.; Yutong, Z. and Shenggao, L. (2015). Assessment of heavy metal pollution and human health risk in urban soils of steel industrial city (Anshan), Liaoning, Northeast China.

Ecotoxicology and Environmental Safety, 120: 377–385. https://doi.org/10.1016/j.ecoenv.2015.06.019

Qingjie, G.; Jun, D.; Yunchuan, X.; Qingfei, W. and Liqiang, Y. (2008). Calculating Pollution Indices by Heavy Metals in Ecological Geochemistry Assessment and a Case Study in Parks of Beijing. Journal of China University of Geosciences, 19(3): 230–241. https://doi.org/10.1016/S1002-0705(08)60042-4

Qu, C.; Sun, K.; Wang, S.; Huang, L. and Bi, J. (2012). Monte Carlo Simulation-Based Health Risk Assessment of Heavy Metal Soil Pollution: A Case Study in the Qixia Mining Area, China. Human and Ecological Risk Assessment: An International Journal, 18(4): 733–750. https://doi.org/10.1080/10807039.2012.688697

Rodríguez Martín, J.A.; De Arana, C.; Ramos-Miras, J.J.; Gil, C. and Boluda, R. (2015). Impact of 70 years urban growth associated with heavy metal pollution. Environmental Pollution, 196: 156–163. https://doi.org/10.1016/j.envpol.2014.10.014

Sakan, S.M.; Đorđević, D.S.; Manojlović, D.D. and Predrag, P.S. (2009). Assessment of heavy metal pollutants accumulation in the Tisza river sediments. Journal of Environmental Management, 90(11): 3382–3390. https://doi.org/10.1016/j.jenvman.2009.05.013

Shakweer, L.M. and Abbas, M.M. (2005). Effect of ecological and biological factors on the uptake and concentration of trace elements by aquatic organisms at Edku Lake. Egyptian Journal of Aquatic Research, 31(1): 271–287. http://www.niof.sci.eg/images/ejar/vol-31/n1/EFFECT%20OF%20ECOLOGICAL%20AND%20BIOLOGICAL%20FACTORS%20ON%20THE%20UPTAKE%20AND%20CONCENTRATION%20OF%20TRACE%20ELEMENTS%20BY%20AQUATIC%20ORGANISMS%20AT%20EDKU%20LAKE.PDF

Sheir, S.K. (2018). Diversity of zooplankton communities at Bahr Shebeen Nilotic canal, El-Menoufia, Egypt: environmental fluctuations or chemical pollution effects? Egyptian Journal of Zoology, 69(69): 175–190. https://doi.org/10.12816/0049669

Sinex, S.A. and Helz, G.R. (1981). Regional geochemistry of trace elements in Chesapeake Bay sediments. Environmental Geology, 3(6): 315–323. https://doi.org/10.1007/BF02473521

Singh, K.P.; Mohan, D.; Sinha, S. and Dalwani, R. (2004). Impact assessment of treated/untreated wastewater toxicants discharged by sewage treatment plants on health, agricultural, and environmental quality in the wastewater disposal area. Chemosphere, 55(2): 227–255. https://doi.org/10.1016/j.chemosphere.2003.10.050

Smith, S.L.; Macdonald, D.D.; Keenleyside, K.A.; Ingersoll, C.G. and Jay Field, L. (1996). A Preliminary Evaluation of Sediment Quality Assessment Values for Freshwater Ecosystems. Journal of Great Lakes Research, 22(3): 624–638. https://doi.org/10.1016/S0380-1330(96)70985-1

Soliman, N.F.; El Zokm, G.M. and Okbah, M.A. (2018). Risk assessment and chemical fractionation of selected elements in surface sediments from Lake Qarun, Egypt using modified BCR technique. Chemosphere, 191: 262–271. https://doi.org/10.1016/ j.chemosphere.2017.10.049

Soliman, N.F.; Younis, A.M. and Elkady, E.M. (2019). An insight into fractionation, toxicity, mobility and source apportionment of metals in sediments from El Temsah Lake, Suez

Canal. Chemosphere, 222: 165–174. https://doi.org/10.1016/j.chemosphere.2019.01.009

Soltan, M.E.; Moalla, S.M.N.; Rashed, M.N. and Fawzy, E.M. (2005). Physicochemical characteristics and distribution of some metals in the ecosystem of Lake Nasser, Egypt. Toxicological & Environmental Chemistry, 87(2): 167–197. https://doi.org/10.1080/02772240500043322

Suresh, G.; Ramasamy, V.; Meenakshisundaram, V.; Venkatachalapathy, R. and Ponnusamy, V. (2011). Influence of mineralogical and heavy metal composition on natural radionuclide concentrations in the river sediments. Applied Radiation and Isotopes, 69(10): 1466–1474. https://doi.org/10.1016/j.apradiso.2011.05.020

Tan, İ. and Aslan, E. (2020). Metal pollution status and ecological risk assessment in marine sediments of the inner Izmit Bay. Regional Studies in Marine Science, 33: 100850. https://doi.org/10.1016/j.rsma.2019.100850

Taylor, S.R. (1964). Abundance of chemical elements in the continental crust: a new table. Geochimica et Cosmochimica Acta, 28(8): 1273–1285. https://doi.org/10.1016/0016-7037(64)90129-2

Tomlinson, D.L.; Wilson, J.G.; Harris, C.R. and Jeffrey, D.W. (1980). Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. Helgoländer Meeresuntersuchungen, 33(1): 566–575. https://doi.org/10.1007/BF02414780

Turekian, K.K. and Wedepohl, K.H. (1961). Distribution of the Elements in Some Major Units of the Earth's Crust. Geological Society of America Bulletin, 72(2): 175–192. https://doi.org/10.1130/0016-7606(1961)72[175:DOTEIS]2.0.CO;2

USDOE (2019). The Risk Assessment Information System (RAIS). Toxicity Profiles. United States Department of Energy. Available from: https://rais.ornl.gov/tox/profiles/Aluminum _ragsa.html; https://rais.ornl.gov/tox/profiles/mn_ragsa.html. Accessed June 2019

USEPA (1989). Risk Assessment Guidance for Superfund. Volume I: Human Health Evaluation Manual (Part A). EPA/540/1-89/002. Interim final. Office of Emergency and Remedial Response, United States Environmental Protection Agency, Washington, D.C. 20450, 291 p. https://www.epa.gov/sites/production/files/2015-09/documents/rags_a.pdf

USEPA (2001). Baseline human health risk assessment: Vasquez Boulevard and I-70 Superfund site, Denver, CO. United States Environmental Protection Agency, Region VIII, Denver CO 80202, 170 p. https://nepis.epa.gov/Exe/ZyPDF.cgi/P1006STM.PDF?Dockey =P1006STM.PDF

USEPA (2002). Supplemental Guidance gor Developing Soil Screening Levels for Superfund Sites. OSWER 9355.4-24. Office of Emergency and Remedial Response, United States Environmental Protection Agency, Washington, DC 20460, 187 p. https://nepis.epa.gov/Exe/ZyPDF.cgi/91003IJK.PDF?Dockey=91003IJK.PDF

USEPA (2007). Dermal exposure assessment: A summary of EPA approaches. EPA/600/R-07/040F. National Center for Environmental Assessment, Office of Research and Development, United States Environmental Protection Agency, Washington, DC 20460, 59 p. http://ofmpub.epa.gov/eims/eimscomm.getfile?p_download_id=469581

USEPA (2011). Exposure Factors Handbook: 2011 Edition (Final Report). EPA/600/R-090/052F. National Center for Environmental Assessment, Office of Research and Development, United States Environmental Protection Agency, Washington, DC 20460, 1466 p. https://www.nrc.gov/docs/ML1400/ML14007A666.pdf

Vasiliu, M. and Dixon, D.A. (2018). Chromium. In: "Encyclopedia of Geochemistry: A Comprehensive Reference Source on the Chemistry of the Earth". White, W.M. (Ed.). Springer International Publishing, Cham, Switzerland: pp. 255–256. https://doi.org/10.1007/978-3-319-39312-4_59

Wang, Z.-X.; Chen, J.-Q.; Chai, L.-Y.; Yang, Z.-H.; Huang, S.-H. and Zheng, Y. (2011). Environmental impact and site-specific human health risks of chromium in the vicinity of a ferro-alloy manufactory, China. Journal of Hazardous Materials, 190(1-3): 980–985. https://doi.org/10.1016/j.jhazmat.2011.04.039

Wei, X.; Gao, B.; Wang, P.; Zhou, H. and Lu, J. (2015). Pollution characteristics and health risk assessment of heavy metals in street dusts from different functional areas in Beijing, China. Ecotoxicology and Environmental Safety, 112: 186–192. https://doi.org/ 10.1016/j.ecoenv.2014.11.005

Wu, P.; Yin, A.; Yang, X.; Zhang, H.; Fan, M. and Gao, C. (2017). Toxic elements in the stream sediments of an urbanized basin, Eastern China: urbanization greatly elevates their adverse biological effects. Environmental Monitoring and Assessment, 189: 167, 113 p. https://doi.org/10.1007/s10661-017-5887-5

Wu, S.; Peng, S.; Zhang, X.; Wu, D.; Luo, W.; Zhang, T.; Zhou, S.; Yang, G.; Wan, H. and Wu, L. (2015). Levels and health risk assessments of heavy metals in urban soils in Dongguan, China. Journal of Geochemical Exploration, 148: 71-78. https://doi.org/ 10.1016/j.gexplo.2014.08.009

Wu, Y.-G.; Xu, Y.-N.; Zhang, J.-H. and Hu, S.-H. (2010). Evaluation of ecological risk and primary empirical research on heavy metals in polluted soil over Xiaoqinling gold mining region, Shaanxi, China. Transactions of Nonferrous Metals Society of China, 20(4): 688–694. https://doi.org/10.1016/S1003-6326(09)60199-0

Xia, F.; Zhang, C.; Qu, L.; Song, Q.; Ji, X.; Mei, K.; Dahlgren, R.A. and Zhang, M. (2020). A comprehensive analysis and source apportionment of metals in riverine sediments of a rural-urban watershed. Journal of Hazardous Materials, 381: 121230. https://doi.org/10.1016/j.jhazmat.2019.121230

Xu, Z.-Q.; Ni, S.-J.; Tuo, X.-G. and Zhang, C.-J. (2008). Calculation of Heavy Metals' Toxicity Coefficient in the Evaluation of Potential Ecological Risk Index. Environmental Science & Technology, 31(2): 112–115. http://en.cnki.com.cn/Article_en/CJFDTotal-FJKS200802029.htm

Yehia, H.M. and Sebaee, E.S. (2012). Bioaccumulation of heavy metals in water, sediment and fish (*Oreochromis niloticus* and *Clarias anguillaris*), in Rosetta branch of the River Nile, Egypt. African Journal of Biotechnology, 11(77): 14204–14216. http://dx.doi.org/ 10.5897/AJB11.3745

Yi, Y.; Yang, Z. and Zhang, S. (2011). Ecological risk assessment of heavy metals in sediment and human health risk assessment of heavy metals in fishes in the middle and lower reaches of the Yangtze River basin. Environmental Pollution, 159(10): 2575–2585. https://doi.org/10.1016/j.envpol.2011.06.011

Yu, R.; Yuan, X.; Zhao, Y.; Hu, G. and Tu, X. (2008). Heavy metal pollution in intertidal sediments from Quanzhou Bay, China. Journal of Environmental Sciences, 20(6): 664–669. https://doi.org/10.1016/S1001-0742(08)62110-5

Zheng, N.; Wang, Q.; Liang, Z. and Zheng, D. (2008). Characterization of heavy metal concentrations in the sediments of three freshwater rivers in Huludao City, Northeast China. Environmental Pollution, 154(1): 135–142. https://doi.org/10.1016/ j.envpol. 2008.01.001