Oceanological and Hydrobiological Studies

International Journal of Oceanography and Hydrobiology

Volume 49, No. 1, March 2020
pages (1-12)

ISSN 1730-413X
eISSN 1897-3191

Risk assessment of heavy metal pollution in water, sediment and plants in the Nile River in the Cairo region, Egypt

by

Afify D.G. Al-Afify,
Amaal M Abdel-Satar*

DOI: **10.1515/ohs-2020-0001**
Category: **Original research paper**
Received: **June 17, 2019**
Accepted: **August 28, 2019**

National Institute of Oceanography and Fisheries, 101 Kasr Al-Ainy St., Cairo, Egypt

Abstract

Samples of water, sediment and two native plants (*Eichhornia crassipes* and *Ceratophyllum demersum*), collected seasonally from eight sites, were analyzed to investigate the level of contamination with metals (Fe, Mn, Ni, Co, Zn, Cu, Cr, Pb and Cd) in the Nile River in the Cairo region, using heavy metal pollution and contamination indices in the case of water, and the geoaccumulation index, the pollution load index, the enrichment factor and the potential ecological risk factor in the case of sediment. The results clarified that the levels of metals among three compartments were in order: sediments > plants > water. The Nile water in Cairo is not critically polluted by the studied metals and the metal pollution index for most sites does not exceed the critical limit (< 100). Sediment samples showed a clear accumulation of Mn, Ni and Cd when compared with benchmarks cited by the Environmental Protection Agency (EPA), especially during low flow seasons. The contribution of Cd to the ecological risk assessment was about 80%, while the contribution of Ni was about 10%, reflecting that these elements originated primarily from anthropogenic sources. *Eichhornia crassipes* and *Ceratophyllum demersum* have a higher accumulation capacity for Mn, Cu and Fe compared to the other studied metals.

Key words: Nile River, water, sediment, plant, heavy metals

* Corresponding author: *abdelsatarmena11@yahoo.com*

DE GRUYTER

The *Oceanological and Hydrobiological Studies* is online at www.oandhs.pl

Introduction

Egypt faces a rapidly increasing deterioration of its surface and groundwater due to the discharges of industrial effluents and domestic wastes into its waterways, which contain harmful or poisonous substances. The excessive application of fertilizers and pesticides in agriculture also causes water pollution problems. Contamination of water caused by different effluent discharges could probably be hazardous to human health (Wahaab & Badawy 2004; Al-Afify et al. 2018).

The Nile River constitutes the main water resource of Egypt. The Nile River in the Cairo region supplies water to a population of approximately 15 million people and supports many commercial and industrial activities. Heavy industry is located around North and South Cairo, in addition to some heavy and small industries located randomly throughout the city.

Water pollution is one of the serious environmental problems resulting from urbanization, overpopulation and industrialization, in addition to ignorance (Narain et al. 2011). A large discharge of heavy metals into the aquatic environment eventually accumulates in water, sediments and dependent biotic components like fish and aquatic plants (Rybak et al. 2013). Heavy metals are of particular concern because of their characteristics such as toxicity, abundance, ubiquity, bioaccumulation capacity and resistance to decomposition. These compounds do not degrade and therefore accumulate in bodies of organisms or sediments, and can pose a significant threat to the health of humans and other plants, animals and ecosystems (Alahabadi & Malvandi 2018). Water contamination with heavy metals is therefore a serious concern in today's world (Miretzky et al. 2004).

Rivers receive sediment from several diffuse and point sources, which is deposited at the bottom and acts as potential sources of metal accumulation in the aquatic food chain through the biomagnification process (Singh et al. 2017). Sediments are considered a sink and reservoir of many toxic contaminants, including heavy metals, and have been used to assess the historical pollution status (Thevenon et al. 2011). Heavy metals can be stored in sediment for a short period of time, where some of these fixed heavy metals may be released into the overlying water and taken up by the aquatic biota (Singh et al. 2017). Many factors, such as temperature, pH and dissolved oxygen levels in water, control the fate of metals through sorption, precipitation and dissolution processes (Duncan et al. 2018).

Aquatic plants play an important role in sequestering large quantities of nutrients and metals from the environment by storing them in the roots and/or shoots. Aquatic plants have high remediation potential for macronutrients due to their general fast growth and high biomass production (Shaltout et al. 2009). Macrophytes are important in the biological monitoring of aquatic ecosystems, because changes in the composition of aquatic vegetation are considered a reliable biological indicator of the water quality. Many studies have researched the use of macrophytes as indicators of bioaccumulation of metals (Pajević et al. 2002; Prasad & Freitas 2003; Vardanyan & Ingole 2006). However, while macrophytes are useful biomonitors, the bioconcentration of metals in macrophytes may result from exposure to metals in both water and/or sediments, making it difficult to directly compare between the concentrations measured in plants and in the environment (i.e. water or sediments).

Unusually high inputs of metals into the aquatic environment have resulted in great financial losses, affected commercial fisheries and in some cases have been hazardous to human health (Banerjee 2003). Research on heavy metals in aquatic environments has become very important due to concerns over accumulation and toxic effects in aquatic organisms and humans through the food chain (Alahabadi & Malvandi 2018).

The most important objectives of this study include: (a) determination of the distribution and concentration of Fe, Mn, Ni, Co, Zn, Cu, Cr Pb and Cd in the water, sediment and macrophytes (*Eichhornia crassipes* and *Ceratophyllum demersum*) in the Nile River in the Cairo region, (b) assessment of the degree of contamination with the studied metals in the river using the heavy metal pollution index and the contamination index in the case of water, and the geoaccumulation index (I_{geo}), the pollution load index (*PLI*), the enrichment factor (*EF*), the potential ecological risk factor (E_r^i) and the risk index (*RE*) in the case of sediment.

Materials and methods

Study area

The Nile is the main source of fresh water in Egypt; its flow rate relies on the available water stored in Lake Nasser to meet the needs defined under the annual water budget of Egypt (Agricultural Policy Reform Program 2002). The Nile River enters Egypt at its southern border with Sudan and runs through a narrow valley (1000 km long) whose width varies from 2 to 20 km. Nile pollutants are derived from different

uncontrolled sources such as agricultural drainage, industrial wastewater and municipal wastewater. The river in the Cairo region receives heavy polluted, treated or partially/untreated industrial drainage water, containing waste from the iron, cement, and sugar industry in the Helwan area. These types of industry tend to pollute the Nile system with heavy metals, suspended matter and organic micropollutants. The main characteristics of the Nile water in the Cairo region are presented in Table 1 and the sampling sites are presented in Figure 1.

Table 1

Main characteristics* of the Nile River water in the Cairo region

Variable	Range	Mean ± SD
Transparency (cm)	35–150	86.97 ± 25.63
Depth (m)	1–10	4.02 ± 0.82
Dissolved oxygen (DO) (mg l^{-1})	4.0–10.26	8.02 ± 1.36
pH	7.32–8.81	8.02 ± 0.30
Alkalinity (mg l^{-1})	92.0–186.5	135.8 ± 25.98
Chloride ion (mg l^{-1})	11.0–88.97	48.51 ± 21.35

*cited after Al-Afify et al. (2018)

Collection of water samples

Subsurface (about 30 cm) water samples were collected using a polyvinyl Van Dorn plastic bottle. Samples were kept in clean stoppered plastic bottles and preserved with 65% HNO_3 to pH < 2. Finally, water samples were digested using 65% HNO_3 according to APHA (2005).

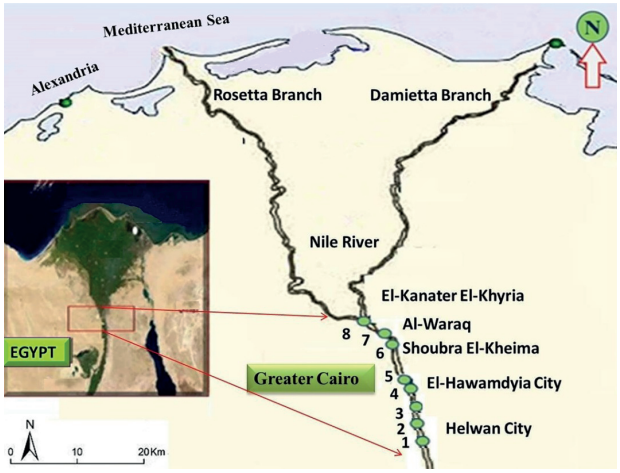

Figure 1

Map of the Nile River showing the sampling sites (after Al-Afify et al. 2018)

Collection of sediment samples

Sediment samples were collected using an Eckman sampling device from the top 20 cm layer of the bottom at eight sampling sites in the Nile River in the Cairo region. Samples were air-dried and stone fragments were removed by passing the dried samples through a 2 mm sieve. The sieved samples were powdered and 0.5 g of finely ground samples was digested according to the method described by Kouadia and Trefry (1987).

Collection of plant samples

Representative macrophytes were sampled at each site according to the type of plant (submerged or floating). The floating macrophyte (*Eichhornia crassipes*) was collected from a 0.5 × 0.5 m quadrant. While the submerged plant (*Ceratophyllum demersum*) was collected using a grab with a known volume.

Plants were rinsed thoroughly with distilled water (four times) and dried at 60°C until completely dry. The dried plant parts were ground and precise weigh (0.50 gram) of each sample was digested using 65% HNO_3, 98% H_2SO_4 and 35% H_2O_2 as prescribed by Saison et al. (2004).

Chemical analysis

Samples (water, sediment and macrophytes) were analyzed for Fe, Mn, Ni, Co, Zn, Cu, Cr Pb and Cd concentrations using an atomic absorption reader (Savant AA-AAS with graphite furnace; GF 5000). The precision of metal analysis was controlled by triplicate readings and the mean value was determined with relative standard deviations below 5%.

Risk assessment of heavy metals in water

Heavy Metal Pollution Index

The suitability of Nile water for the drinking purpose with respect to metals was determined using the heavy metal pollution index (*HPI*). It is based on the weighted arithmetic quality mean method as presented in the following equation (Prasad & Bose 2001; Mohan et al. 1996):

$$HPI = \frac{\sum_{i=1}^{n} Q_i W_i}{\sum_{i=1}^{n} W_i}$$

where Q_i is the individual quality rating of the i^{th} metal and calculated as follows:

$$Q_i = \frac{C_i}{C_S} \times 100$$

While W_i is calculated as $1/C_s$, where C_s is the recommended standard of the relevant metal and n is the number of metals estimated. C_i is the estimated value of the metals in µg l^{-1}. The permissible standard value (C_s) for each metal was taken from WHO (2011) and Egyptian drinking water quality standards (EWQS 2007). For drinking water, the critical heavy metal pollution index score is 100, above which the overall pollution level should be considered unacceptable for drinking water (Prasad & Mondal 2008).

The Contamination Index (C_d)

C_d indicates the relative contamination of different metals separately and manifests the combined effects of all metals. It is calculated using the following equation (Backman et al. 1997):

$$C_d = \sum_{i=1}^{n} C_{fi}$$

where C_{fi} is calculated according to the following equation:

$$C_{fi} = \frac{C_i}{C_s} - 1$$

C_{fi} is the contamination factor for the i^{th} metal, C_i is the measured value for the i^{th} metal and C_s is the upper permissible value of the i^{th} metal. The resultant C_d values are grouped into three classes: low (C_d < 1), medium (C_d = 1–3) and high (C_d > 3). C_s is formerly introduced in the *HPI* calculation.

Risk assessment of heavy metals in sediment

The geoaccumulation index *I-geo,* the pollution load index (*PLI*), the modified contamination degree (mC_d), the enrichment factor (*EF*) and the potential ecological risk index (*ER*) were used to assess the metal pollution status.

Geoaccumulation index

The *I-geo* was computed as follows (Muller 1969):

$$I - geo = log_2\left(\frac{C_n}{1.5B_n}\right)$$

where C_n is the total metal concentration in the sediment sample; B_n is the metal background value, and 1.5 is the factor for the background matrix correction. Concentrations of heavy metals as defined in the freshwater sediment benchmarks (EPA 2006) were used as background. The *I-geo* consists of seven classes (Table 2).

Enrichment factor

The *EF* of a single trace element in the sediments was calculated as follows (Yahaya et al. 2012):

$$EF = \frac{\left(\frac{M}{Fe}\right)_{sample}}{\left(\frac{M}{Fe}\right)_{background}}$$

Fe was used as a conservative tracer to differentiate natural from anthropogenic components. $(M/Fe)_{sample}$ is the ratio of a metal and Fe concentration in a sample in the examined environment and $(M/Fe)_{background}$ is the ratio of a metal and Fe concentration of the background (Yahaya et al. 2012). The classification of *EF* values is presented in Table 2.

Pollution Load Index

PLI was evaluated as follows (Tomlinson et al. 1980):

$$PLI = \left(Cf_1 \times Cf_2 \times Cf_3 \times ... \times Cf_n\right)^{\frac{1}{n}}$$

where *n* is the number of elements and *Cf* is the contamination factor, which is the ratio between the element level (C_i) in sediment samples and its background concentration (B_i). Background concentrations of heavy metals were taken from freshwater sediment benchmarks (EPA 2006):

$$Cf_i = \frac{C_i}{B_i}$$

where a *PLI* value > 1 indicates a contaminated site, while a *PLI* value < 1 indicates no contamination.

Modified contamination degree (mC_d)

The mC_d was introduced to estimate the overall degree of contamination at a given site according to the formula (Abrahim & Parker 2008):

Table 2

Geoaccumulation index (*I-geo*), enrichment factor (*EF*) and modified contamination factor for elements and contamination levels

Index						
Geoaccumulation index (*I-geo*)			Enrichment factor (*EF*)		Modified contamination degree (mC_d)	
Class no.	*I-geo* value	Contamination level	*EF* value	Contamination level	mC_d value	Contamination level
0	$I\text{-}geo \leq 0$	practically unpolluted	$1 < EF < 3$	minor enrichment	$mC_d < 1.5$	nil pollution
1	$0 < I\text{-}geo < 1$	unpolluted to moderately polluted	$3 < EF < 5$	moderate enrichment	$1.5 \leq mC_d < 2$	low pollution
2	$1 < I\text{-}geo < 2$	moderately polluted	$5 < EF < 10$	moderately severe enrichment	$2 \leq mC_d < 4$	moderate pollution
3	$2 < I\text{-}geo < 3$	moderately to heavily polluted	$10 < EF < 25$	severe enrichment	$4 \leq mC_d < 8$	high pollution
4	$3 < I\text{-}geo < 4$	heavily polluted	$25 < EF < 50$	very severe enrichment	$8 \leq mC_d < 16$	very high pollution
5	$4 < I\text{-}geo < 5$	heavily to extremely polluted	$EF \geq 50$	ultra-high	$16 \leq mC_d < 32$	extremely high pollution
6	$I\text{-}geo \geq 5$	extremely polluted			$mC_d \geq 32$	ultra-high pollution

$$mC_d = \frac{\sum_{i=1}^{n} Cf}{n}$$

where n = the number of analyzed elements, i = the i^{th} element and Cf = the contamination factor. The classifications of mC_d are presented in Table 2.

Potential Ecological Risk Index (*ER*)

The potential ecological risk index (*ER*) was introduced to assess the degree of heavy metal pollution in sediments according to the toxicity of heavy metals and the response of the environment, where ER is calculated as the sum of all risk factors (E_r^i) for heavy metals in sediments (Hakanson 1980; 1988):

$$ER = \sum_{i=1}^{n} E_r^i$$

and

$$E_r^i = C_f \times T_r^i$$

where E_r^i is the monomial potential ecological risk factor, Cf is the contamination factor, and T_r^i is the toxicity response factor of a heavy metal. The factor scores on each heavy metal according to Hakanson's (1980) approach were as follows: Mn (1), Zn (1), Cu (5), Ni (5), Co (2), Pb (5), Cd (30) and Cr (2). The pollution levels according to *ER* and E_r^i values are presented in Table 3.

Risk assessment of heavy metals in plants

The ability of plants to absorb and accumulate metals from the aqueous growth media was assessed using the bioconcentration factor (*BCF*). The *BCF* value is calculated as the ratio of metal concentrations in the plant and the associated water, where higher *BCF* values reveal high accumulation ability of the plant:

$$BCF = \frac{[metal]_{plant}}{[metal]_{water}}$$

Statistical analysis

Correlations among metal concentrations in water, plants and sediment samples were estimated using Pearson correlation coefficients ($p < 0.01$). In addition,

Table 3

Pollution levels according to ER and E_r^i values

E_r^i scope	Ecological risk levels for single factor pollution	*ER* scope	Potential ecological risk levels
$E_r^i < 40$	Low	$ER < 150$	Low grade
$40 \leq E_r^i < 80$	Moderate	$150 \leq ER < 300$	Moderate
$80 \leq E_r^i < 160$	Considerable	$300 \leq ER < 600$	Severe
$160 \leq E_r^i < 160$	High	$600 \leq ER$	Serious
$320 \leq E_r^i$	Serious	-	-

data obtained from water and sediment samples were examined for significant differences among different seasons and sites using the ANOVA test.

Results and discussion

Table 4 summarizes the range, mean concentrations and standard deviation of Fe, Mn, Ni, Co, Zn, Cu, Cr, Pb, and Cd in river water in different seasons. At most sites, the concentrations of Fe, Cu, Zn, Pb, Co and Cd in different seasons were higher than the CCME (2007) threshold limits established to protect water quality for aquatic life. Pb and Cd concentrations in the Nile water were several times higher than the limits recommended by CCME (2007), where cadmium has lethal effects on aquatic biota such as crustaceans (Effendi et al. 2016). Ni is the only metal whose concentration in water is still at a safe level for aquatic life according to CCME (2007) limits.

The calculated ranges of *HPI* values in different seasons are presented in Table 4 in relation to the standards endorsed by EWQS (2007) and WHO (2011) for drinking water. The *HPI* measurements at sites 4 and 8 in the summer season exceeded the critical metal pollution index of 100 proposed by Prasad & Mondal (2008) for drinking water, identifying potential dangerous effects on the Nile water environment. However, the *HPI* for most studied sites does not exceed the critical limit indicating that the Nile water in the Cairo region is not critically polluted with respect to metals (Abdel-Satar et al. 2017). No significant differences ($p > 0.05$) were found among seasons or among sites for the metal pollution index.

Table 4

Seasonal variation of heavy metals (µg l^{-1}) compared with different criteria and HPI values in the Nile water in the Cairo region

		Autumn	Winter	Spring	Summer	CCME (2007)	WHO (2011)	EWQS (2007)
Fe	Range	642.0–1090.0	775.0–1300.0	403.0–862.0	196.0–690.0	300	1000	300
	Mean ± SD	869.0 ± 169.6	1005.8 ± 166.4	566.6 ± 142.7	433.25 ± 165.13			
Mn	Range	97.81–234.81	96.46–287.68	90.79–161.5	87.33–121.24	-	400	100
	Mean ± SD	152.2 ± 44.7	191.7 ± 61.9	124.9 ± 25.0	97.9 ± 10.5			
Ni	Range	9.54–20.54	11.89–26.47	9.04–25.41	8.45–17.68	65	70	20
	Mean ± SD	12.79 ± 3.87	16.51 ± 5.32	16.48 ± 5.78	11.94 ± 3.19			
Co	Range	4.85–20.54	6.95–22.63	9.51–24.35	8.45–21.35	1	-	-
	Mean ± SD	13.45 ± 5.30	14.75 ± 5.30	16.39 ± 5.85	13.99 ± 4.83			
Zn	Range	22.56–75.48	28.91–98.56	24.35–36.55	18.34–42.18	30	4000	3000
	Mean ± SD	38.97 ± 17.34	38.97 ± 17.34	31.74 ± 4.58	29.87 ± 9.49			
Cu	Range	6.45–18.40	6.15–19.42	7.05–14.12	5.12–9.45	2	2000	2000
	Mean ± SD	11.71 ± 4.14	10.44 ± 4.48	10.65 ± 3.10	7.47 ± 1.38			
Cr	Range	9.47–17.96	8.79–20.68	10.69–21.34	9.75–16.58	-	50	50
	Mean ± SD	12.28 ± 3.03	13.99 ± 3.72	14.24 ± 3.84	12.42 ± 2.12			
Pb	Range	5.75–12.45	4.15–12.15	4.01–9.85	3.15–18.47	2	10	10
	Mean ± SD	9.18 ± 2.18	7.26 ± 2.72	6.13 ± 1.89	9.65 ± 5.60			
Cd	Range	1.98–2.98	1.45–2.98	1.75–3.15	1.98–3.84	0.18*	3	3
	Mean ± SD	2.35 ± 0.37	2.26 ± 0.54	2.40 ± 0.55	2.79 ± 0.69			
HPI^1	Range	61.3–96.3	46.8–88.7	56.6–96.7	64.3–104.2			
HPI^2	Range	64.3–99.0	53.3–90.4	64.3–96.7	66.4–104.1			

HPI^1: according to WHO (2011); HPI^2: according to EWQS (2007); *according to CCME (2014)

Concerning the metal pollution, the Nile water in Cairo can be categorized as having a low level of metal pollution (Cd < 1), except site 4 in the winter season (low flow) when water is moderately polluted by metals (Cd ≤ 3) according to EWQS (2007) limits (Fig. 2). Therefore, severe precautions at the anthropogenic input sites should be taken to control the influx of elements.

The concentrations of heavy metals in sediment from different sites at the Nile River are presented in Table 5. As shown in Tables 4 and 5, the levels of heavy metals in the Nile sediment were much higher than those in water and showed enrichment with metals in the Nile sediment.

There is a significant difference between the seasons ($p < 0.05$) for Fe, Mn, Zn, Cu, Pb concentrations, where metal concentrations were higher in the cold seasons than in the summer due to the lower water flow during the cold seasons, which could facilitate the accumulation of the metals in the sediment (Islam et al. 2015; Abdel-Satar et al. 2017).

The average concentrations of heavy metals in sediments were in descending order: Fe > Mn > Zn > Ni > Cr > Cu > Pb ≈ Co > Cd. The high level of Cr recorded at site 4 (54.65, 52.56, 48.97 and 47.52 mg kg^{-1} in autumn, winter, spring and summer, respectively), exceeding the freshwater sediment EPA benchmarks, indicates its higher input, which may originate from urban and industrial waste (Mohiuddin et al. 2012).

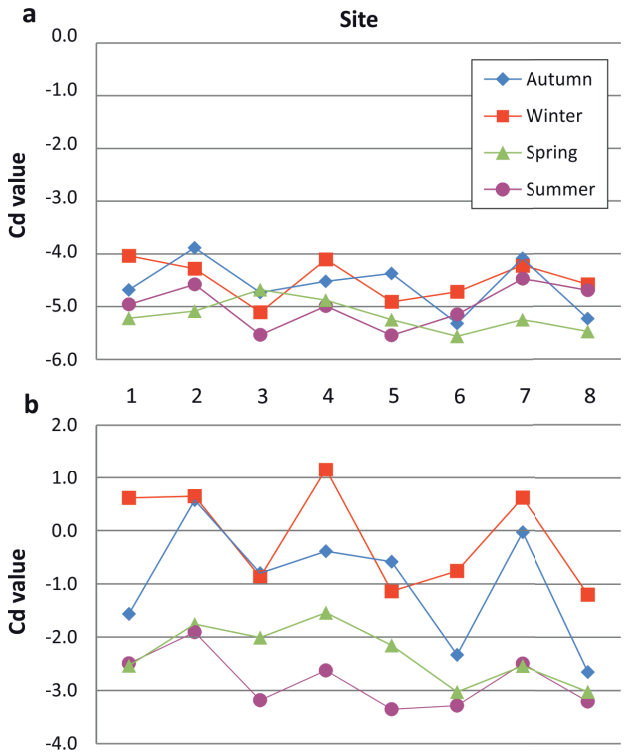

Figure 2

Contamination index values (*Cd*) of the Nile River according to a) WHO and b) EWQS criteria

Table 5

Heavy metals distribution (μg g^{-1}) compared with EPA (2006), contamination factor (*Cf*) and PLI values in the Nile sediment in the Cairo region.

Metal		Autumn	Winter	Spring	Summer	EPA (2006)	*Cf*
Fe	Range	27154–53468	18238–25014	17548–26481	17185–25678	20000	0.86–2.67
	Mean ± SD	38858 ± 9784	22774 ± 2166	21121 ± 2878	19217 ± 2862		1.27 ± 0.47
Mn	Range	283.0–1334.0	339.0–988.0	273.0–456.0	512.0–984.0	460	0.59–2.90
	Mean ± SD	849.3 ± 354.4	708.0 ± 215.2	326.8 ± 58.5	754.4 ± 174.4		1.43 ± 0.64
Zn	Range	45.00–122.45	58.70–120.00	46.32–70.00	62.40–97.50	121	0.37–1.01
	Mean ± SD	84.44 ± 27.82	77.34 ± 19.69	60.06 ± 8.54	83.66 ± 12.05		0.63 ± 0.17
Cu	Range	18.70–30.45	19.50–27.89	19.85–25.91	10.80–20.15	31.6	0.34–0.96
	Mean ± SD	25.49 ± 4.24	23.61 ± 2.77	22.58 ± 2.20	14.31 ± 3.22		0.68 ± 0.17
Ni	Range	28.38–87.12	27.95–80.52	24.75–72.85	32.52–67.85	22.7	1.09–3.84
	Mean ± SD	50.44 ± 20.19	50.94 ± 19.39	47.94 ± 16.75	45.06 ± 13.23		2.14 ± 0.74
Co	Range	7.19–19.50	7.40–20.45	5.40–17.85	7.56–17.64	50	0.11–0.41
	Mean ± SD	13.06 ± 4.11	12.95 ± 4.92	11.20 ± 4.00	11.27 ± 3.65		0.24 ± 0.08
Cr	Range	16.85–54.65	18.96–52.56	13.67–48.97	14.52–47.52	43.4	0.31–1.26
	Mean ± SD	25.27 ± 12.83	28.11 ± 12.93	26.85 ± 11.37	25.44 ± 11.23		0.61 ± 0.27
Pb	Range	6.52–18.41	9.50–25.12	10.00–30.33	5.86–11.50	35.8	0.16–0.85
	Mean ± SD	12.12 ± 4.23	16.82 ± 4.47	18.83 ± 8.18	7.85 ± 1.83		0.39 ± 0.18
Cd	Range	2.05–3.19	1.74–3.21	1.86–3.42	2.14–3.24	0.99	1.76–3.45
	Mean ± SD	2.75 ± 0.45	2.51 ± 0.53	2.74 ± 0.50	2.62 ± 0.40		2.68 ± 0.46
PLI	Range	0.76–1.08	0.72–1.05	0.73–0.97	0.56–0.73		

For most sites, especially during the low flow seasons, the concentrations of Mn, and Ni were higher than the freshwater sediment benchmarks of EPA (2006). However, the levels of Cd were significantly higher than the benchmarks for all sites in different seasons.

Pearson's correlation matrix for the analyzed sediment elements showed a significant positive correlation between Ni, Co and Cr (Table 6), suggesting similar sources of input (human or natural) for these elements in the Nile River sediment. High correlations between the same elements (Ni, Co and Cr) in water (Table 6) may reflect similar levels of contamination or/and release from the same sources of pollution, identical behavior during their transport in the Nile system and mutual interactions (Ali et al. 2016; Abdel-Satar et al. 2017).

The results of the *I-geo* index are shown in Figure 3. According to the classification provided by Müller (1969), the calculated *I-geo* values showed that most of the elements studied (Fe, Zn, Cu, Co, Pb and Cr) at all sites were included in the zero class (i.e. practically uncontaminated), while Mn was included in class 0 for all sites except sites 2 and 3, where it was included in class 1 (uncontaminated to moderately contaminated). Ni and Cd had the highest *I-geo* values and were included in classes 1 and 2.

The enrichment factor (*EF*) is an appropriate index to distinguish between natural and anthropogenic sources of elements. Accordingly, *EF* values of less than 1.5 represent the natural origin and EF values greater than 1.5 represent the anthropogenic origin of an element (Chen et al. 2015; Alahabadi & Malvandi 2018). The *EF* results showed that the mean values of the index were > 1.5 for Ni and Cd at all sites in different seasons (Table 7), indicating that these elements originated primarily from anthropogenic sources. On the other hand, Zn, Cu, Co, Cr and Pb at all sites originated from natural sources (*EF* values < 1.5). The lowest *EF* values were recorded for Mn in the summer season (*EF* < 1.5), while in the autumn, winter and spring the *EF* values at some sites were greater than 1.5. According to the *EF*, most of the studied samples were categorized as class 1 with minor enrichment with metals (1 < *EF* < 3).

Another index to assess the contamination of elements in the Nile River sediments in the Cairo region is the pollution load index. The resulting *PLI* values are presented in Table 5 and range from

Table 6

Correlation between the elements in water and sediments of the Nile River in the Cairo region

	Fe	Mn	Zn	Cu	Ni	Co	Pb	Cd	Cr
Water									
Fe	1.00								
Mn	–0.02	1.00							
Zn	–0.30	–0.24	1.00						
Cu	0.20	0.05	0.19	1.00					
Ni	–0.13	0.23	0.07	–0.20	1.00				
Co	–0.29	0.13	0.27	–0.09	0.75*	1.00			
Pb	0.17	0.07	0.14	0.66*	–0.46	–0.40	1.00		
Cd	–0.06	–0.06	0.09	–0.01	–0.02	0.12	–0.11	1.00	
Cr	–0.20	0.15	0.19	–0.21	0.83*	0.73*	–0.41	0.15	1.00
Sediment									
Fe	1.00								
Mn	0.52	1.00							
Zn	0.14	0.34	1.00						
Cu	0.53*	0.16	0.06	1.00					
Ni	0.18	–0.08	–0.20	–0.23	1.00				
Co	0.10	–0.15	–0.09	–0.20	0.84*	1.00			
Pb	–0.04	–0.18	–0.32	0.54*	–0.35	–0.47	1.00		
Cd	0.01	–0.24	–0.03	–0.05	0.29	0.48*	–0.24	1.00	
Cr	–0.01	–0.13	–0.16	–0.20	0.85*	0.81*	–0.36	0.33	1.00

*Correlation is significant at $p < 0.01$; $n = 32$

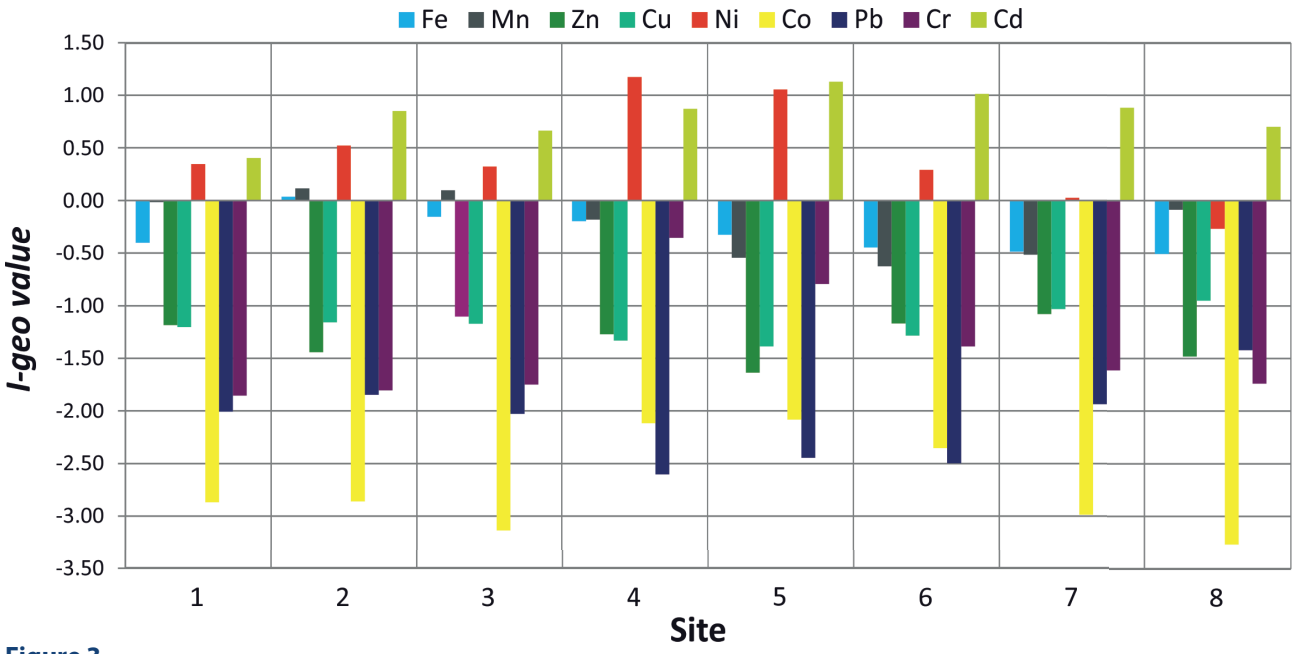

Figure 3

I-geo values for metals in the Nile sediment

0.56 to 1.08. The values of the *PLI* index were < 1 at all sites except sites 4 and 5 in the winter season, which showed that the concentration of the studied elements was lower than the background values and therefore were categorized as being uncontaminated. Consequently, there is no serious concern about contamination with these elements. The contamination factor (*Cf*) values for Fe, Mn, Zn, Cu, Co, Pb and Cr showed a moderate degree of contamination ($1 \leq Cf < 3$) at different sites and in different seasons (Table 5), whereas the *Cf* values for Ni and Cd showed a slightly high degree of contamination ($Cf > 3$) for some sites in different seasons. The range of mC_d values (0.78–1.48) determined for the analyzed elements indicates very low levels of contamination at all sites (Fig. 4).

The average potential ecological risk (ER) was categorized as low-grade risk (ER < 150), viewed from the overall perspective of the study (Fig. 5). The contribution of Cd to the ecological risk assessment was about 80%, while the contribution of Ni was about 10%. The contribution of the other six investigated metals was as follows: Mn – 1.5%, Zn – 0.6%, Cu – 3.5%, Co – 0.5%, Pb – 2.0% and Cr – 1.2%. Consequently, Cd contained in the Nile sediment surface may have a significant ecological effect. Based on the monomial ecological risk index (E_r^i), the E_r^i values of the eight investigated heavy metals indicated that all values

Table 7

Enrichment factor for the studied elements in the Nile River in the Cairo region

		Mn	Zn	Cu	Ni	Co	Pb	Cr	Cd
Autumn	Range	0.35–1.54	0.17–0.70	0.33–0.65	0.78–1.96	0.06–0.22	0.10–0.38	0.15–0.57	0.87–2.21
	Mean ± SD	0.95 ± 0.34	0.38 ± 0.17	0.43 ± 0.11	1.22 ± 0.47	0.14 ± 0.06	0.18 ± 0.09	0.31 ± 0.14	1.54 ± 0.57
Winter	Range	0.66–1.82	0.44–0.88	0.55–0.79	1.15–3.03	0.13–0.34	0.23–0.76	0.34–0.99	1.76–2.81
	Mean ± SD	1.34 ± 0.36	0.56 ± 0.15	0.65 ± 0.09	2.03 ± 0.74	0.23 ± 0.08	0.46 ± 0.20	0.56 ± 0.23	2.22 ± 0.42
Spring	Range	1.16–2.21	0.49–0.91	0.53–0.81	1.18–2.95	0.11–0.35	0.23–0.73	0.32–0.97	2.02–3.35
	Mean ± SD	1.57 ± 0.38	0.66 ± 0.16	0.68 ± 0.11	2.06 ± 0.68	0.21 ± 0.08	0.46 ± 0.18	0.58 ± 0.22	2.64 ± 0.57
Summer	Range	0.58–1.14	0.43–0.66	0.30–0.73	1.44–3.16	0.15–0.37	0.13–0.37	0.29–1.10	2.05–3.42
	Mean ± SD	0.75 ± 0.16	0.52 ± 0.07	0.48 ± 0.15	2.15 ± 0.61	0.24 ± 0.08	0.23 ± 0.07	0.61 ± 0.27	2.79 ± 0.47

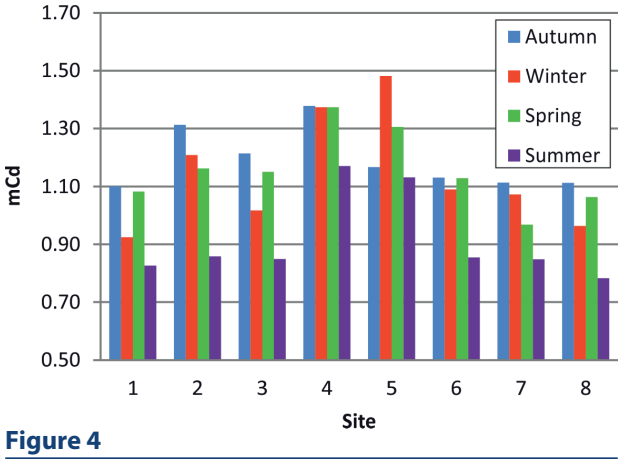

Figure 4

mCd values for different sites in the Nile sediment

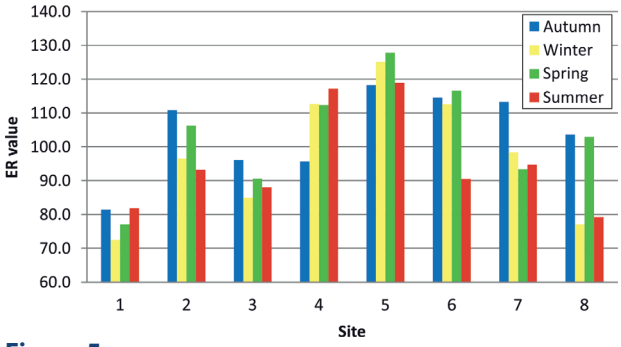

Figure 5

ER values for different sites in the Nile sediment

were burdened with low ecological risk (< 40) except Cd values, which showed a moderate ecological risk ranging from 52.7 to 103.6 (Table 8). No significant differences ($p > 0.05$) were observed between the ER values in different seasons, while high significant differences were recorded between the sites ($p < 0.01$), with site 5 showing the highest values in different seasons.

Concentrations of the metals in the two plants from the Nile River are listed in Figure 6. The distribution of most studied elements between water, sediment and plants at different sites showed a similar trend: sediment > plants > water. Fe was the most frequently accumulated metal in the two plants, followed by Mn, Zn, Cu, Ni, Co, Cr and Pb, whereas Cd was the least frequently accumulated one. The results show a significant increase in the level of most of the studied metals in *E. crassipes* and *C. demersum* compared to water samples. BCF values for metals were ranked as follows: Cu > Mn > Fe > Ni > Co > Zn > Pb ≈ Cr > Cd and Mn > Cu > Fe > Ni > Pb ≈ Zn > Cr ≈ Co > Cd in *E. crassipes* and *C. demersum*, respectively (Fig. 7). The bioaccumulation of Cu and Mn was several times higher than the accumulation of the other studied elements in *E. crassipes* and *C. demersum*.

There were differences in the sequences of the studied metal levels in the macrophytes compared to the sequences of their bioaccumulation ability. These differences indicate a different capacity of macrophytes for different metals (Kastratovi et al. 2014). Factors involved in the identification of such differences include ionic exchange, the rate of chelation, translocation of element ions, chemical precipitation and precipitation induced by microorganisms or by root exudates (Pajević et al. 2008).

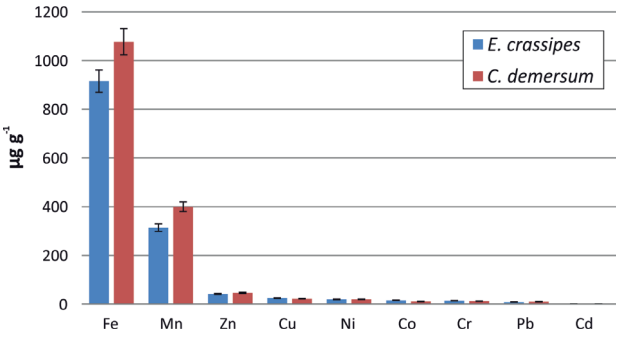

Figure 6

Average distribution of metals in *E. crassipes* and *C. demersum* in the Nile River in the Cairo region

Conclusions

The distribution of most studied metals between water, sediment and plants at different sites showed a similar trend: sediment > plants > water. Pb and Cd concentrations in the Nile water were several times higher than CCME recommended limits, while Ni is the only metal whose concentration in water is still at

Table 8

E_r^i ranges and the average contribution (%) to the ecological risk

	Mn	Zn	Cu	Ni	Co	Pb	Cd	Cr
Min.	0.59	0.37	1.71	5.45	0.22	0.82	52.73	0.63
Max	2.90	1.01	4.82	19.19	0.82	4.24	103.64	2.52
Contribution (%)	1.5	0.6	3.5	10.7	0.5	2.0	80.0	1.2

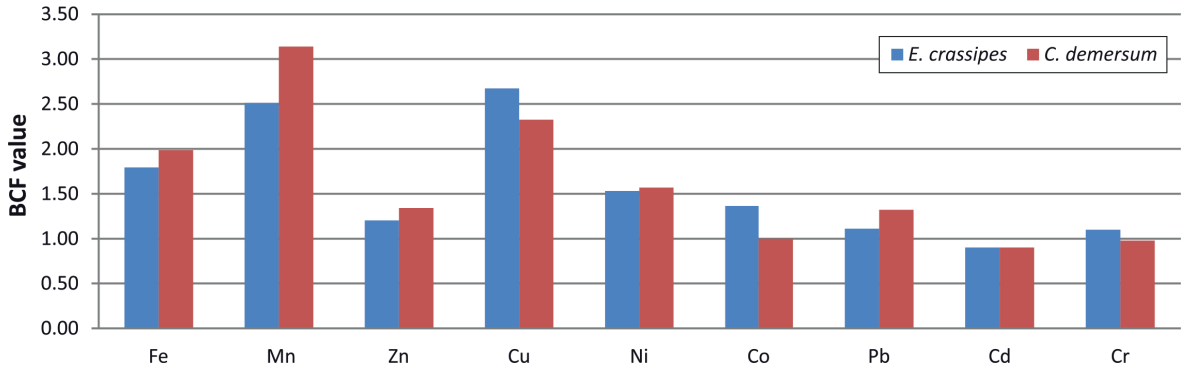

Figure 7

Average BCF in *E. crassipes* and *C. demersum* in the Nile River in the Cairo region

a safe level for aquatic life. The Nile water in Cairo is not critically polluted by the studied metals and the HPI and the contamination index for most sites do not exceed the critical limit according to WHO and EWQS.

The geoaccumulation index (*I-geo*), the enrichment factor (*EF*), the pollution load index (*PLI*) and the contamination factor (*Cf*) showed that the Nile sediments are contaminated with Cd, Ni and Mn, and the Cd levels in the Nile sediments are significantly higher for all sites than the EPA freshwater sediment benchmarks, while Mn and Ni levels exceeded the limits during the low flow seasons. The contribution of Cd to the ecological risk assessment was about 80%, while the contribution of Ni was about 10%, reflecting that these elements originated primarily from anthropogenic sources.

The BCF values for metals were ranked as follows: Cu > Mn > Fe > Ni > Co > Zn > Pb ≈ Cr > Cd and Mn > Cu > Fe > Ni > Pb ≈ Zn > Cr ≈ Co > Cd in *E. crassipes* and *C. demersum*, respectively. The bioaccumulation of Cu and Mn was several times higher than the accumulation of the other studied elements in *E. crassipes* and *C. demersum*.

References

Abdel-Satar, A.M., Ali, M.H.H & Goher, M.E. (2017). Indices of water quality and metal pollution of Nile River, Egypt. *Egypt. J. Aqua. Res.* 43: 21–29.

Al-Afify, A.D.G., Othman, A.A. & Ramadan, M.A. (2018). Characterization of chemical and microbiological quality of Nile River surface water at Cairo (Egypt). *Rend. Fis. Acc. Lincei.* 29: 725–736.

Alahabadi, A. & Malvandi, H. (2018). Contamination and ecological risk assessment of heavy metals and metalloids in surface sediments of the Tajan River, Iran. *Mar. Pollut. Bull.* 133: 741–749.

Ali, M.M., Ali, M.L., Islam, M.S. & Rahman, M.Z. (2016). Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh. Environ. *Nano., Monit. & Manage.* 5: 27–35.

APHA (American Public Health Association). (2005). American Water Works Association. Standard methods for the examination of water and wastewater. New York.

APRP (Agricultural Policy Reform Program). (2002). Water Policy Program, Survey of Nile System Pollution Sources. Report No. 64.

Backman, B., Bodis, D., Lahermo, P. & Rapant S. (1997). Application of a groundwater contamination index in Finland and Slovakia. *Environ. Geol.* 36(1–2): 55–64.

Banerjee, A.D.K. (2003). Heavy metal levels and solid phase speciation in street dusts of Delhi, India. *Environ. Pollut.* 123: 95–105.

CCME (Canadian Council of Ministers of the Environment). (2007). For the protection of aquatic life 2007. In: Canadian Environmental Quality Guidelines, 1999, Canadian Council of Ministers of the Environment, 1999, Winnipeg.

CCME (Canadian Council of Ministers of the Environment). (2014). Canadian Water Quality Guidelines: Cadmium. Scientific Criteria Document. Canadian Council of Ministers of the Environment, Winnipeg. ISBN 978-1-77202-000-7 PDF.

Chen, H., Teng, Y., Lu, S., Wang, Y. & Wang, J. (2015). Contamination features and health risk of soil heavy metals in China. *Sci. Total Environ.* 512: 143–153.

Coci, M., Nicol, G.W, Pilloni, G.N., Schmid, M., Kamst-van Agterveld M.P. et al. (2010). Quantitative assessment of ammonia-oxidizing bacterial communities in the epiphyton of submerged macrophytes in Shallow Lakes. *Appl. Environ. Microbiol.* 76: 1813–1821.

Duncan, A.E., de Vries, N. & Nyarko, K.B. (2018). Assessment of Heavy Metal Pollution in the Sediments of the River Pra and Its Tributaries. *Water Air Soil Pollut.* 229(8): 272.

Effendi, H., Kawaroe, M., Mursalin & Lestari, D.F. (2016). Ecological risk assessment of heavy metal pollution in

surface sediment of Mahakam Delta, East Kalimantan. *Proc. Environ. Sci.* 33: 574–582.

EPA (Environmental Protection Agency). (2006). Region III BTAG Freshwater Sediment Screening Benchmarks 8/2006.

EWQS (Egyptian drinking water quality standards). (2007). Ministry of Health, Population Decision number 458.

Hakanson, L. (1980). An ecological risk index for aquatic pollution control. A sedimentological approach. *Water Res.* 14: 975–1001.

Hakanson, L. (1988). Metal monitoring in coastal environments, In U. Seeliger, L.D. Lacerda & S.R. Patchineelam (Eds.), *Metals in Coastal Environments of Latin America* (pp. 240–257). Springer Verlag.

Islam, M.S., Ahmed, M.K., Habibullah-Al-Mamun, M. & Hoque, M.F. (2015). Preliminary assessment of heavy metal contamination in surface sediments from a river in Bangladesh. *Environ. Earth Sci.* 73: 1837–1848.

Jensen, S.I., Kuhl, M. & Prieme, A. (2007). Different bacterial communities associated with the roots and bulk sediment of the seagrass *Zostera marina*. *FEMS. Microbiol. Ecol.* 62: 108–117.

Kastratović, V., Krivokapić, S. Bigović, M., Đurović, D. & Blagojević, N. (2014), Bioaccumulation and translocation of heavy metals by *Ceratophyllum demersum* from the Skadar Lake, Montenegro, *J. Serb. Chem. Soc.* 79(11): 1445–1460.

Kouadia, L. & Trefry, J.H. (1987). Saline trace metal contamination in the Ivory. *Air Water Soil Pollut.* 32: 145–154.

Miretzky, P., Saralegui, A. & Cirelli, A.F. (2004). Aquatic macrophytes potential for the simultaneous removal of heavy metals (Buenos Aires, Argentina). *Chemosphere* 57(8): 997–1005.

Mohan, S.V., Nithila, P. & Reddy, S.J. (1996). Estimation of heavy metal in drinking water and development of heavy metal pollution index. *J. Environ. Sci. Health A* 31(2): 283–289.

Mohiuddin, K.M., Otomo, K., Ogawa, Y. & Shikazono, N. (2012). Seasonal and spatial distribution of trace elements in the water and sediments of the Tsurumi River in Japan. *Environ. Monit. Assess.* 184: 265–279.

Müller, G. (1969). Index of geo-accumulation in sediments of the Rhine River. *Geol. J.* 2: 109–118.

Narain, S., Ojha, C.S.P., Mishra, S.K., Chaube, U.C. & Sharma, P.K. (2011). Cadmium and chromium removal by aquatic plant. *Int. J. Environ. Sci.* 1: 1297–1304.

Pajević, S., Borišev, M., Rončević, S., Vukov, D. & Igić, R. (2008). Heavy metal accumulation of Danube River aquatic plants – indication of chemical contamination. *Cent. Eur. J. Biol.* 3(3): 285–294.

Pajević, S., Vučković, M., Stanković, Ž., Krstić, B., Kevrešan, Ž. et al. (2002). The content of some macronutrients and heavy metals in aquatic macrophytes of three ecosystems connected to the Danube in Yugoslavia. *Archiv für Hydrobiologie, Large Rivers* 13: 73–83.

Prasad, B. & Bose, J.M. (2001). Evaluation of heavy metal pollution index for surface and spring water near a limestone mining area of the lower Himalayas. *Environ. Geol.* 41: 183–188.

Prasad, B. & Mondal, K.K. (2008). The impact of filling an abandoned opencast mine with fly ash on ground water quality: a case study. *Mine Water Environ.* 27(1): 40–45.

Prasad, M.N.V. & Freitas, H.M. (2003). Metal hyperaccumulation in plants – Biodiversity prospecting for phytoremediation technology. *Electro. J. Biotechnol.* 6(3): 286–290.

Rybak, A., Messyasz, B., & Łęska, B. (2013). The accumulation of metal (Co, Cr, Cu, Mn and Zn) in freshwater Ulva (Chlorophyta) and its habitat. Ecotoxicology 22(3): 558–573.

Saison, C., Schwartz, C. & Morel, J.L. (2004). Hyperaccumulation of metals by *Thlaspi caerulescens* as affected by root development and Cd-Zn/Ca-Mg ineraction. *Intl. J. phytoremediation* 6(1): 49–61.

Shaltout, K.H., Gala, T.M. & El-Komi, T.M. (2009). Evaluation of the Nutrient Status of Some Hydrophytes in the Water Courses of Nile Delta. *Egypt. J. Bot.* 2009: 1–12.

Singh, H., Pandey, R., Singh, S.K. & Shukla, D.N. (2017). Assessment of heavy metal contamination in the sediment of the River Ghaghara, a major tributary of the River Ganga in Northern India. *Appl. Water Sci.* 7: 4133–4149.

Thevenon, F., Graham, N.D., Chiaradia, M., Arpagaus, P., Wildi, W. et al. (2011). Local to regional scale industrial heavy metal pollution recorded in sediments of large freshwater lakes in central Europe lakes Geneva and Lucerne over the last centuries. *Sci. Total Environ.* 412: 239–247.

Vardanyan, L.G. & Ingole B.S. (2006). Studies on heavy metal accumulation in aquatic macrophytes from Sevan (Armenia) and Carambolim (India) lake systems. *Environ. Int.* 32: 208–218.

Wahaab, R.A. & Badawy, M.I. (2004). Water Quality Assessment of the River Nile System: An Overview. *Biomed. Environ. Sci.* 17: 87–100.

WHO (World Health Organization). (2011). Guidelines for drinking-water quality, fourth ed. Geneva: WHO, 564p. ISBN: 978 92 4 154815 1.

Yahaya, M.I., Jacob, A.G., Agbendeh, Z.M., Akpan, G.P. & Kwasara, A.A. (2012). Seasonal potential toxic metals contents of Yauri river bottom sediments: North western Nigeria. *J. Environ. Chem. Ecotoxicol.* 4(12): 212–221.