Plant Archives Vol. 18 No. 2, 2018 pp. 2131-2144 **e-ISSN:2581-6063 (online), ISSN:0972-5210**

MACROPHYTES POTENTIAL FOR REMOVAL OF HEAVY METALS FROM AQUATIC ECOSYSTEM, EGYPT : USING METAL ACCUMULATION INDEX (MAI)

Yasser A. El-Amier[1]*, Muhammad A. El-Alfy[2] and Manar M. Nofal[3]

[1]Department of Botany, Faculty of Science, Mansoura University, Mansoura, Egypt.
[2]Department of Marine Pollution, National Institute of Oceanography and Fisheries (NIOF), Egypt.
[3]Egyptian Environmental Affairs Agency (EEAA), Mansoura, Egypt.

Abstract

Analysis of the capacity of aquatic plants in north and south sectors of Idku Lake in two seasons for heavy metals removal was studied. The order of metals were; Fe > Pb > Co > Cr > Cd > Ni and Fe > Ni > Co > Pb > Cd > Cr in sediments and water, respectively. Ecological risk (Er) showed low potential risk for metals in all stations (< 40) and very high risk for Cd (> 320). The risk index (RI) showed very high ecological risk (> 600). Pollution load index (PLI) was low nearby El-Boughaz and very high in drainage water areas. Accumulation of metals in hydrophytes was; E. *crassipes* (Fe, Ni, Co, Cd, Pb, Cr); *E. stagnina* (Cd and Co); *P. australis* (Fe, Pb) and *T. domingensis* (Cr and Ni). Order of metal accumulation index (MAI) is *P. australis>E. crassipes>T. domingensis>E. stagnina*. The study revealed suitable plant species as phytoaccumulators.

Key words : Phytoremediation, metal ions, pollution indices, Idku Lake.

Introduction

Coastal lagoons are particular ecosystems where many interests may conflict, from fisheries to tourism, and from aquaculture to harbor facilities or urban development. The importance of these lagoons has not always been well understood and their ecological functioning must be analyzed and evaluated in the context of a specific type of water body with its own characteristics (Pérez-Ruzafa *et al*., 2010).

Lake Idku is one of the northern Delta lakes of Egypt and once considered to be among the most productive lakes of Egypt. It is shallow, brackish and subject to huge inputs of terrigenous and anthropogenic nutrients from drains discharge, sewage and agricultural runoff (Saeed, 2013). In the last decades, the reduction in lake area occurred as a result of the development of drainage and irrigation schemes in the eastern portion. The lake characterized by different vegetation communities i.e. *Phragmites*, *Eichhornia* and *Potamogeton* species. The worsening of aquatic environments is attributed to industrial, agricultural and municipal wastes which directly added to the water bodies especially those lakes which considered as the important habitat of organisms i.e. fishes (Schindler *et al*., 1995; Abdullah *et al*., 2007).

Environmental pollution is a consequence of the impressive growth in population, industry and agriculture, and water pollution in particular has increasingly become a worldwide phenomenon. Waste water discharge contains various kinds of pollutants, including household, agricultural and industrial chemicals. Inadequate or absence of waste water treatment facilities, particularly in developing countries, are failing to prevent such pollutants moving into the environment (Alcamo *et al*., 2007).

There are two types of pollutant sources namely; point and non-point source pollutants; the point source is easier to control, more readily identifiable and measurable and generally more toxic. Non point sources of pollution are the significance of agricultural activities (e.g. irrigation and drainage, applications of pesticides and fertilizers,

---

****Author for correspondence :*** E-mail: yasran@mans.edu.eg

runoff and erosion); urban and industrial runoff; erosion associated with construction; mining and forest harvesting activities; pesticide and fertilizer applications. Point sources include hazardous spills, underground storage tanks, storage piles of chemicals, mine-waste ponds, deep-well waste disposal, industrial or municipal waste out falls, runoff and leachate from municipal and hazardous waste dumpsites and septic tanks (Loague and Corwin, 2005).

Toxic metal pollution of waters and soils was a major environmental problem. The mean problem concerned with water pollution was heavy metals when water containing these metals, as pollutants, it will contaminate and enrich sediments (Mireles *et al*., 2004). Heavy metals have a great ecological significance, due to their toxicity and accumulative behavior. These elements, contrary to most pollution, are not biodegradable and undergo a global eco-biological cycle, in which natural water is the main pathways (Hassouna, 1989; Jaishankar *et al*., 2014).

There are three main pathways through which heavy metals enter into the environment. These routes include disposal of metal enriched sewage sludge and sewage effluents into water bodies, occur as by-products from metal mining processes and deposition of atmospheric particulates. These metals are transported through water bodies as either dissolved metals in water and sometimes as an integral part of suspended sediments. The dissolved heavy metals in water have the greatest potential of causing the most deleterious effects. The metal pollutants in aquatic ecosystems usually remain either insoluble or suspension form and finally tend to settle down to the bottom or are taken up by organisms. The progressive and irreversible accumulation of these metals in various organs of aquatic creatures ultimately leads to metal-related diseases because of their toxicity and thereby endangering the aquatic biota (Obodai *et al*., 2011).

The biomonitoring of pollutants using accumulator species is based on the capacity with which some plant and animal have to accumulate relatively large amounts of certain pollutants, even from many diluted solutions without obvious noxious effects. Biomonitoring has several advantages and is the most significant study of sub-lethal levels of bioaccumulated contaminants within the tissues of anorganism, which indicate the net amount of pollutants integrated over a period of time (Qunfang *et al*., 2008; Venkatesha *et al*., 2013). This work is undertaken with the aim of accessing the concentrations of certain HMs (Fe, Cd, Co, Cr, Ni and Pb) in four common aquatic species in Idku Lake, Egypt, selecting the best aquatic species for single HM accumulation using bioaccumulation factor (BAF), evaluating the total accumulation capacities of HMs for selected aquatic species using metal accumulation index (MAI) and providing qualified data for further investigations of HMs phytoremediation in the impacted contaminated areas within HMs.

Materials and Methods

Study area

Idku Lake is located in the North West of the Nile delta and connected with the Mediterranean Sea through Boughaz El-Maadia canal (fig. 1), it is located between latitudes 31° 10′ and 31° 18′ North and longitudes 30° 23′ and 30° 8′ east. Idku Lake receives its water from two sources; the drainage water of Kom Belag and Bersik drains and the sea water.

Sampling

Water and sediment samples were collected from 12 sites distributed within the lake two basins in northern and southern parts in two different seasons (winter and summer). Preservation of samples is according to APHA (1992).

Heavy metal analysis

Sediment

Samples were air dried, sieved, using 0.75 mm plastic sieve and digested for about two hours in a mixture of 3:2:1 nitric acid (HNO_3), perchloric acid ($HClO_4$) and hydrochloric acid (HCl), respectively as described by (Oregioni and Astone, 1984). In the filtered aqueous solution, six heavy metals (Fe, Ni, Cr, Pb, Cd and Co) were measured using Atomic Absorption Spectrophotometer (ASS). The results were expressed as μg/g.

Water

The samples were filtered using 0.45 um membrane filters. Solvent extraction was utilized using ammonium pyrrolidinedi-thiocarbamate (APDC) and methyl isobutyl ketone (MIBK). Where, water samples were pre-concentrated with APDC-MIBK extraction procedure as described by standard methods (APHA, 1989). Heavy metals in the obtained solution were measured using the Flame Atomic Absorption Spectrophotometer (AAS: Perkin Elmer Analyst 100). The results were expressed as μg/l.

Plant

In the study area, aquatic plant species (n=4) were collected from north and south sector of the lake, marked properly and packed in polyethylene bags. Nomenclature and identification of plant species were carried out

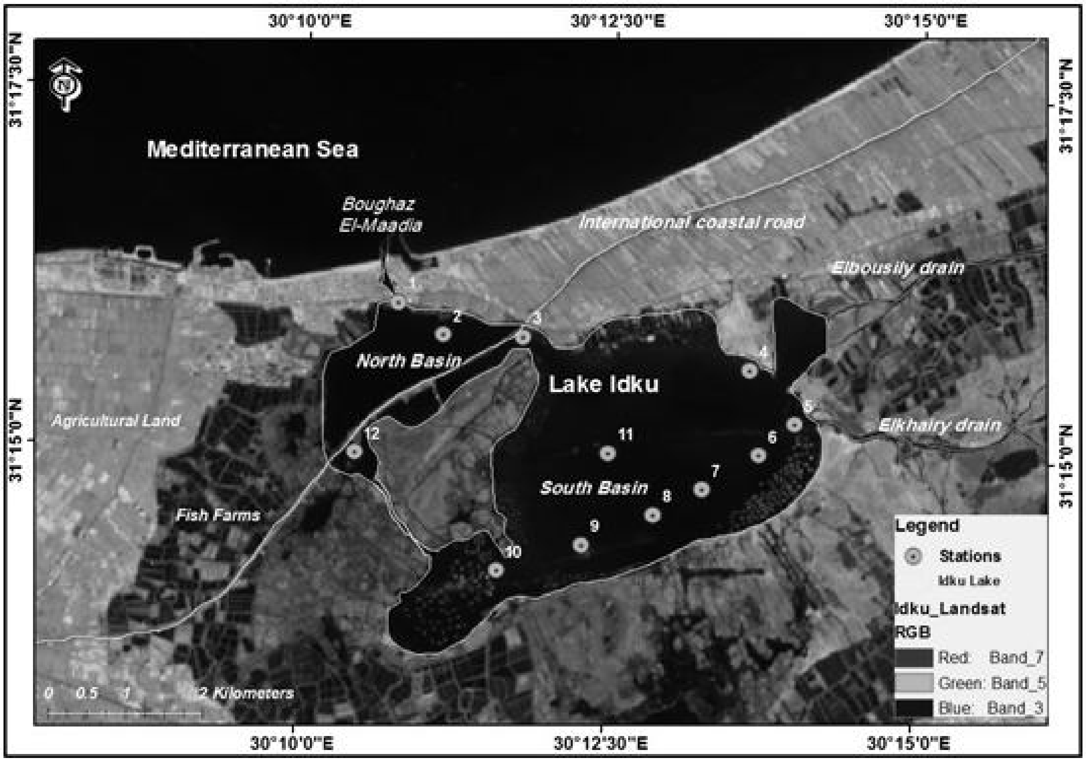

Fig. 1 : Map showing sampling sites within Idku Lake, Egypt.

according to Tackholm (1974) and Boulos (1999 & 2005). All plants were washed and cleaned with tape water, oven dried at 50°C and ground into powder with anelectric grinder. For metal analyses, 0.1 g (dry weight) of plant samples was added to Teflon beakers and digested with HNO_3/H_2O_2 (3:1 v/v) at 70 to 90°C during which temperatures were raised to approximately 95°C until evolution of nitrous gas had stopped and the digest became quite clear. The digests were diluted with distilled water up to a known volume (Allen *et al.*, 1974). Fe, Cd, Co, Cr, Niand Pb were estimated using Atomic Absorption Spectrometer (A Perkin-Elemer, Model 2380, USA).

Ecological risk assessment

The ecological risk assessment was carried out using two risk indices *viz*. potential ecological risk index (RI) and pollution load index (PLI). The potential ecological risk index (RI) was developed using equations of Hakanson (1980) and Zhu (2008).

$$RI = \sum_{1}^{n} Er$$

$$Er = Tr \times CF$$

Where, Er is the single index of ecological risk factor, and n is the count of the heavy metal species, Tr = toxic response factor suggested by Hakanson (1980) for five metals Cd (30), Co (5), Pb (5), Ni (5) and Cr (2).

The PLI provides some understanding to the public of the area about the quantity of a component in the environment. The PLI of a single site is the root of anumber (n) of multiplied together Contamination Factor (CF) values. The level of contamination for individual metal can be expressed by the contamination factor (CF) (Tomlinson *et al.*, 1980).

$$CF = C\ metal\ /\ C\ background$$

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

Where, CF is the single contamination factor and n is the count of the elements present.

Bioaccumulation factor (BAF)

The bioaccumulation factor (BAF) was calculated for heavy metals. BAF determines the ability of a plant to uptake a metal from soils. In this study, the BAF value for heavy metals are calculated with the following equations :

$$BAFshoot = Cshoot\ /\ Csoil$$

Where, C_{shoot} and C_{soil} represent the metal concentrations in the shoots and soil, respectively (Ma *et al.*, 2001; Yoon *et al.*, 2006).

Metal accumulation index (MAI)

The metal accumulation index (MAI) was used to

Table 1 : The description of used indices of metals.

Index	Value	Category
CF	<1	Low contamination
	$1 \leq CF < 3$	Moderate contamination
	$3 \leq CF < 6$	Considerable degree of contamination
	$CF \geq 6$	Very high contamination
PLI	<1	No Pollution
	>1	Polluted
Er	<40	Low potential ecological risk
	$40 \leq Er < 80$	Moderate potential ecological risk
	$80 \leq Er < 160$	Considerable potential ecological risk
	$160 \leq Er < 320$	High potential ecological risk
	$Er \geq 320$	Very high ecological risk
RI	<150	Low ecological risk
	$150 \leq RI < 300$	Moderate ecological risk
	$300 \leq RI < 600$	Considerable ecological risk
	$RI > 600$	Very high ecological risk.

assess the overall performance of heavy metal accumulation in the plants.

$$MAI = \sum_{j=1}^{N} Ij$$

$$Ij = X / \Sigma X$$

N is the total number of metals analyzed and Ij is the sub-index for variable j. Ij can be further defined, where x is the mean concentration of an element and Σx is its standard deviation (Liu *et al.*, 2007; Monfared *et al.*, 2013).

Statistical analyses

The analysis of heavy metal in soil, water and plant samples were done in triplicates and the mean values were separated based on Duncan's test at 0.05 probability level, using COSTAT 6.3 program. The heavy metals were subjected to one-way ANOVA (SPSS 16 for Windows) to analyze the correlation between heavy metals in the plant, water and soil.

Results and Discussion

Heavy metal content in sediment and water

Surface sediment is the most important reservoir of metals and other pollutants in aquatic environments (Penga *et al.*, 2008). Altun *et al.* (2009) stated that release and adsorption of metals in sediments of the lake are dependent upon physical properties of saltwater inflow, freshwater inputs and accumulation and degradation of organic matter. Contaminated sediments can pose a threat to aquatic life, human health and the environment (Saeed and Shaker, 2008). The pollution by heavy metals in water is associated with agricultural, industrial and municipal discharges into water resources. In the water column, metals may be taken up by living organisms, deposited in the sediments or remain for a period in the water itself (Vazquez *et al.*, 1994; Zaghloul, 2001).

The order of heavy metals in Lake sediments is as follow: Fe > Pb > Co > Cr > Cd > Ni. Where in water, it was as follow; Fe > Ni > Co > Pb > Cd > Cr. Average concentrations of heavy metals for sediments and water from the different stations of the study area in summer and winter seasons are presented in Tables 2 and 3.

Iron is present in organic wastes and plant debris in sediments. Different activities in the environment may have a strong impact on its occurrence in water (Taha *et al.*, 2004). Fe in sediments ranged between 276.42 and 962.39 with amean value of 506.05 µg/g. While the mean concentrations of iron in water varied from 14.03 to 50.31 µg/l with amean value of 34.18 µg/l. The highest values of iron are related to organic wastes from different drains. It higher than the standard limit of EPA (2002) of 15 µg/g. but within the limits in water (300 µg/l).

Nickel showed variable distribution between different stations. As in sediment, it ranged between 6.38 and 19.7 with a mean value of 14.11 µg/g. in water samples, it varied from 1.26 to 9.37 with amean value of 5.10 µg/l. it's obvious that the lowest mean value of Ni is in the northern sector. But its highest mean concentration is recorded in drainage areas affected by agricultural drainage water from Bersik drain in the southern sector. As agricultural wastes especially phosphates are significant sources of nickel in sediments (McGrath, 1995). The mean concentration of Ni in sediments is within the limits of CSQG (2007) and EPA (2002).

Natural sources of cobalt in the environment are from soil, dust or seawater (Kesler and Simon, 2015). It varied from 11.91 to 43.09 with amean value of 23.75 µg/g in sediment. In water, it varied from 0.19 to 7.83 with amean value of 4.58 µg/l. it's obvious that the highest mean concentration of Co is recorded at sites 4 and 7 in eastern and southern parts of the lake may attribute to industrial processes wastes that use the metal or its compounds or from the wastes of phosphatic fertilizers (Kesler and Simon, 2015; El-Alfy *et al.*, 2017). The highest value of cobalt in sediments is more than the limit of CSQG (2007).

The Cr content of sediments increases due to pollution from various sources of which the main ones

Table 2 : The concentrations of heavy metals in the hydrosoils of Idku Lake during summer and winter season. Values are significant at *P ≤ 0.05, ** P ≤ 0.01, *** P ≤ 0.001.

Metal (μg/g)	Season	No. of sites												Mean	$LSD_{0.05}$
		1	2	3	4	5	6	7	8	9	10	11	12		
Fe	S	474.03	427.86	317.85	319.26	269.43	770.5	755.58	920.19	712.11	317.25	96.39	568.71	495.76	56.39**
	W	444.27	155.46	283.38	295.26	370.71	1154.28	770.94	784.5	516.48	438.96	456.45	525.42	516.34	59.25**
	M	459.15	291.66	300.62	307.26	320.07	962.39	763.26	852.35	614.30	378.11	276.42	547.07	506.05	57.01**
Ni	S	24.58	16.65	14.96	15.96	0.86	19.23	16.91	13.65	11.49	12.19	10.41	10.89	13.98	1.54**
	W	14.23	2.80	21.83	18.18	11.95	32.82	20.76	25.74	3.80	4.34	19.10	1.86	14.23	1.81***
	M	19.41	9.73	18.40	17.07	6.41	26.03	18.84	19.70	7.65	8.27	14.76	6.38	14.11	1.61**
Cd	S	16.31	14.08	8.73	7.39	15.55	1.89	12.56	9.25	5.44	30.77	5.89	35.09	13.58	1.71***
	W	15.90	5.33	24.56	23.53	24.04	24.43	23.30	20.54	13.56	19.94	15.03	4.89	15.90	1.96***
	M	16.11	9.71	16.65	15.46	19.80	13.16	17.93	14.90	9.50	25.36	10.46	19.99	14.74	1.68***
Co	S	6.67	8.55	10.39	43.76	24.42	20.78	33.88	29.14	23.88	7.53	22.45	2.96	19.54	2.35***
	W	27.96	31.05	52.33	42.42	42.74	45.36	41.22	34.97	31.77	28.55	33.97	20.86	27.96	3.80**
	M	17.32	19.80	31.36	43.09	33.58	33.07	37.55	32.06	27.83	18.04	28.21	11.91	23.75	2.99**
Cr	S	2.53	13.19	33.72	23.52	25.46	21.08	38.81	34.25	40.15	28.7	14.47	29.03	25.41	2.83***
	W	19.23	25.96	16.34	16.45	29.11	20.19	10.8	28.14	10.49	24.68	17.39	5.8	18.72	2.50***
	M	10.88	19.58	25.03	19.99	27.29	20.64	24.81	31.20	25.32	26.69	15.93	17.42	22.07	2.33***
Pb	S	11.2	1.535	17.07	26.29	18.71	34.02	39.05	30.45	20.97	13.57	7.73	26.54	20.59	2.38***
	W	25.31	35.07	30.47	41.05	57.89	44.03	44.79	44.39	47.36	46.27	47.56	30.87	41.25	4.32**
	M	18.26	18.30	23.77	33.67	38.30	39.03	41.92	37.42	34.17	29.92	27.65	28.71	30.92	3.26***

S: Summer; W : Winter; M : Mean.

Table 3: The concentrations of heavy metals in water of Idku Lake during summer and winter season. Values are significant at *P ≤ 0.05, ** P ≤ 0.01, ***P ≤ 0.001.

Metal (µg/l)	**Season**	**No. of sites**												**Mean**	$\mathbf{LSD_{0.05}}$
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**		
Fe	S	12.29	10.84	13.79	40.26	13.34	11.18	15.72	17.93	17.63	11.12	29.3	30.97	18.70	2.13***
	W	48.23	34.33	14.28	59.9	71.57	27.14	84.89	59.97	40.33	75.94	43.87	35.53	49.67	5.5.0***
	M	30.26	22.585	14.035	50.08	42.455	19.16	50.305	38.95	28.98	43.53	36.585	33.25	34.18	3.69***
Ni	S	0.03	2.77	1.33	0.87	2.85	1.95	0.73	0.18	3.01	0.04	3.94	2.47	1.68	0.22**
	W	13.82	6.92	1.82	5.31	5.14	16.79	9.36	6.96	11.72	9.52	14.74	0.04	8.51	1.01**
	M	6.93	4.85	1.58	3.09	4.00	9.37	5.05	3.57	7.37	4.78	9.34	1.26	5.10	0.59**
Cd	S	2.94	1.67	1.36	0.79	0.3	1.85	1.72	1.12	1.28	1.8	1.45	1.79	1.51	0.17**
	W	0.68	0.55	0.66	2.28	0.06	1.78	1.76	2.11	0.58	3.63	2.63	1.84	1.55	0.19***
	M	1.81	1.11	1.01	1.54	0.18	1.82	1.74	1.62	0.93	2.72	2.04	1.82	1.53	0.17**
Co	S	6.62	7.6	10.72	3.55	0.72	5.07	6.17	2.81	6.2	4.97	0.02	1.23	4.64	0.57***
	W	5.87	3.15	3.69	7.66	4.96	5.19	9.49	4.48	0.42	8.88	0.36	0.05	4.52	0.56***
	M	6.25	5.38	7.21	5.61	2.84	5.13	7.83	3.65	3.31	6.93	0.19	0.64	4.58	0.53***
Cr	S	0.91	1.58	5.4	2.19	0.49	1.12	0.11	2.64	4.38	1.55	0.07	0.51	1.75	0.24***
	W	0.02	1.42	0.6	0.04	0.55	2.05	0.04	0.39	0.31	2.18	0.4	1.13	0.76	0.11***
	M	0.47	1.50	3.00	1.12	0.52	1.59	0.08	1.52	2.35	1.87	0.24	0.82	1.25	0.16***
Pb	S	8.66	6.45	10.96	12.26	3.64	2.39	6.05	0.89	0.83	0.02	5.09	2.93	5.01	0.65***
	W	1.25	0.64	6.32	2.91	9.57	4.2	4.14	2.98	3.21	5.14	6.5	1.78	4.05	0.48**
	M	4.96	3.55	8.64	7.59	6.61	3.30	5.10	1.94	2.02	2.58	5.80	2.36	4.53	0.52**

S: Summer; W: Winter; M: Mean.

Table 4 : Pollution indices (Er, RI and PLI)in thesediment of Idku Lake during summer and winter seasons.

No. of sites	Ecological Risk (Er)					(RI)	PLI
	Ni	Cd	Co	Cr	Pb		
1	1.45	1610.4	4.55	0.24	4.55	1621.19	0.50
2	0.7	970.5	5.2	0.44	4.6	981.44	0.43
3	1.35	1664.4	8.25	0.56	5.95	1680.51	0.61
4	1.25	1545.9	11.35	0.44	8.4	1567.34	0.64
5	0.45	1979.4	8.85	0.6	9.6	1998.9	0.59
6	1.9	1316.1	8.7	0.46	9.75	1336.91	0.80
7	1.4	1793.1	9.9	0.56	10.5	1815.46	0.82
8	1.45	1489.5	8.45	0.7	9.35	1509.45	0.81
9	0.55	950.1	7.3	0.56	8.55	967.06	0.57
10	0.6	2535.6	4.75	0.6	7.5	2549.05	0.57
11	1.1	1046.1	7.4	0.36	6.9	1061.86	0.50
12	0.45	1998.9	3.15	0.38	7.2	2010.08	0.48

RI: ecological risk index; PLI: pollution load index.

are attributable to industrial wastes such as Cr pigment and tannery wastes, electroplating sludge, leather manufacturing wastes, and municipal sewage sludge (Mondol *et al.*, 2011). Cr in sediments of study area ranged between 10.88 and 27.29 with amean value of 22.07 µg/g. in water, it varied from 0.24 to 3 with amean value of 1.25 µg/l. values of Cr in sediments of the lake are within CSQG (2007) of (64µg/g) and EPA (2002) limit of (150 µg/g) and in water of (100 µg/l). The untreated municipal wastes being discharged into the lake are the main sources of Cr in contaminated sites (El-Serehy *et al.*, 2012).

Cadmium is a trace element in phosphatic fertilizers. Atmospheric deposition is also an important source of cadmium pollution (ATSDR, 2008). In sediments, it ranged between 9.5 and 25.39 with amean value of 14.74 µg/g. Cd is found in marine waters mostly in the dissolved form (Stankovic *et al.*, 2012). It ranged between 0.18 and 2.04 with amean value of 1.53 µg/l. The highest concentrations of Cd is related to the different chemicals being used in agricultural activities like pesticides and phosphate fertilizers (Yahya *et al.*, 2018). For sediment, values of Cd are higher than EPA (2002) limit (6 ìg/g) and CSQG (2007) of (1.4 µg/g). While in water, its mean value is within EPA (2002) limit (2.37 µg/l). Cd is serious to aquatic life, even at low concentration. When it present in sediment in high concentration, the uptake through food will increase.

Lead enters the aquatic environment through precipitation of lead dust fallout, erosion and leaching of soil, municipal and industrial waste discharges (EPA, 1977). .Pb ranged between 18.26 and 41.92 with amean value of 30.92 µg/g in sediment samples. Its highest mean value was observed in site 7 besides drainage areas, also it may relate to the decayed of dead aquatic plants which add Pb to the sediments (Abdo, 2005). While it ranged between 1.94 and 8.64 with amean value of 4.53 µg/l in water samples. Higher levels of Pb occur in water bodies near highways and large cities due to high gasoline combustion (Banat *et al.*, 1998). The mean values of Pb in sediments are within CSQG (2007) of (70 µg/g) and EPA (2002). For water, it was within the EPA standard limit.

Metals as lead, chromium and nickel have interacted with organic matter in the aqueous phase and settled to the bottom, resulting in a high concentration of these metals in the sediment (Gohar, 1998; Abida *et al.*, 2009).

The concentration of metals in the sediment was higher than in the water which may be attributed to the fact that suspended heavy metals in the water column settle in the sediments and accumulate within time (Obodai *et al.*, 2011). The nature of soil particulates in the southern sector characterized by fine and clayey particles, providing the greatest potential for adsorption (Jickells and Knap, 1984). Furthermore the presence of organic matter. All these reasons aid to increase concentrations and binding of metals in these parts. In contrast, these sediments nearby El-Boughaz are sandy with low content of metals.

Ecological risk assessment

From table 3, the ecological risk values were in low potential ecological risk for all metals in all stations (< 40), except for Cd which showed very high ecological risk (> 320). The risk index values recorded very high ecological risk (> 600). According to pollution load index categories if (PLI < 1) indicate non-significant impact and (PLI > 1), anindication to pollution; from the results of PLI and according to table 3, it indicates less significant pollution. The lowest value of PLI was obtained in station one nearby El-Boughaz that may relate to the dilution of pollutants with the sea water. While the highest value of PLI was obtained in stations 6, 7 and 8; while these areas most impacted by drainage waters from El-Khairy and Bersik drain which contains organic and inorganic wastes from different pollutant sources.

Heavy metals in plants

Plants are important components in ecosystems because they transfer elements from the abiotic environment to the biotic one (Martínez-López *et al.*, 2014). The concentrations of Fe, Cd, Cr, Co, Ni and Pb (mg.kg^{-1} dry weight) were analyzed in tissues of the hydrophytes *E. crassipes* (free floating), *E. stagnina*, *P. australis* and *T. domingensis* (emergent hydrophytes)

Table 5 : The concentration of heavy metals and bioaccumulation factors in tissues of studied hydrophytes during summer and winter seasons in north and south sectors of Idku Lake.

Plant species	Season	Heavy metal (mg.kg^{-1})											
		North sector						South sector					
		Fe	**Ni**	**Cd**	**Co**	**Cr**	**Pb**	**Fe**	**Ni**	**Cd**	**Co**	**Cr**	**Pb**
E. crassipes	Summer	84.00	0.17	0.95	3.01	1.94	3.31	52.43	18.39	2.33	7.48	1.68	1.16
	Winter	29.11	0.36	7.67	2.73	0.40	1.10	19.91	20.74	6.99	6.46	4.15	3.66
	Mean	56.56	0.27	4.31	2.87	1.17	2.21	36.17	19.57	4.66	6.97	2.92	2.41
	BAF	1654.38	52.01	2816.99	626.64	932.27	486.75	1058.07	3840.04	3045.75	1521.83	2322.71	532.01
E. stagnina	Summer	41.34	3.81	1.63	1.77	0.14	4.17	31.09	19.06	11.89	2.22	3.40	2.42
	Winter	115.80	4.48	2.44	9.29	1.05	0.56	78.31	32.58	2.02	1.83	1.23	1.19
	Mean	78.57	4.15	2.04	5.53	0.60	2.37	54.70	25.82	6.96	2.03	2.32	1.81
	BAF	155.26	293.76	138.06	232.84	26.96	76.49	108.09	1829.91	471.85	85.26	104.89	58.38
P. australis	Summer	135.95	5.32	0.63	1.54	0.35	6.65	122.30	36.42	1.73	2.64	1.45	4.75
	Winter	200.27	7.77	0.93	2.37	0.69	9.56	186.62	38.87	2.03	3.46	1.79	5.66
	Mean	168.11	6.55	0.78	1.96	0.52	8.11	154.46	37.65	1.88	3.05	1.62	5.21
	BAF	332.20	463.86	52.92	82.32	23.56	262.13	305.23	1667.97	127.54	128.42	73.40	168.34
T. domingensis	Summer	249.84	18.24	3.36	5.50	0.10	2.76	208.90	23.11	5.73	8.63	2.13	2.27
	Winter	62.65	9.05	1.40	3.79	1.67	1.47	43.41	16.80	3.64	6.45	2.60	3.77
	Mean	156.25	13.65	2.38	4.65	0.89	2.12	126.16	19.96	4.69	7.54	2.37	3.02
	BAF	308.75	967.04	161.47	195.58	40.10	68.40	249.29	2414.25	317.84	317.47	107.16	97.67

collected from north and south sectors along the Idku Lake in two seasons (summer and winter). The uptake of heavy metal ions by aquaticplants depended on the plant species and the metal (table 5). The results of the heavy metal analysis revealed that the hydrophytes were enriched with Fe as the most abundant metal followed by Ni>Co>Cd>Pb>Cr as depicted in table 5. The concentrations and mean of heavy metals in aquatic plants in summer and winter seasons at north and south sectors of Idku Lake are listed in table 3.

T. domingensis had the highest concentrations for each of the heavy metals among the studied hydrophytes in summer and winter seasons along the north and south sectors of Idku Lake. During the summer season, the highest concentrations of Crin *E. crassipes* reached 1.94 and 1.68 in the plant samples, which are collected from North and South, respectively. On the other hand, the concentrations of Cr during the winter season were 0.4 and 4.15 in North and South of the lake, respectively. Human activities such as discharge industrial and household wastes are anon-natural source of Cr (Jaishankar *et al*., 2014).

During the summer season, the highest concentrations of Pb in *P. australis* reached 6.65 and 4.75 in the plant samples which are collected from North and South, respectively. On the other hand, the concentrations of Pb during the winter season were 9.56 and 5.66 in North and South of the lake, respectively. Typically, concentrations of Pb in plants are less than 10 mg/kg (Kabata-Pendias and Pendias, 2001; Padmavathiamma and Li, 2007). Positive relationships between atmospheric heavy metal deposition and heavy metal concentrations in plants have been identified (Ugulu *et al*., 2012). It is likely that plants can readily take up atmospheric Pb after deposition on the leaves due to anthropogenic activities, but Pb translocation from plant roots to leaves is not a major pathway for Pb uptake (Turer *et al*., 2001; Hu *et al*., 2014).

Bioaccumulation factor (BAF)

Mean values of bio-accumulation factor (BAF) determined for heavy metals in aquatic plant samples are shown in table 5 and fig. 3. According to BAF data, the capacity of hydrophytes for accumulating considerable amounts of metals depends on species-speciûc characteristics of plants and ion content of water (Kadukin, 1982; Sood, 2012). The *E. crassipes* (floating hydrophytes) had the highest accumulation for each of the heavy metals among the studied hydrophytes in seasonal mean concentration along the north and south sectors of Idku Lake. The maximum mean of Cd and Co BAF in the north sector (138.06 and 232.84, respectively) and Cd in the south sector (471.89) were observed to be related to *E. stagnina*, while Co in the south sector the highest accumulation (317.47) was observed in *T. domingensis*. For Fe, Pb the maximum BAF values (332.20 and 262.13, respectively) along the Lake were found in *P. australis*. For Cr and Ni, *T. domingensis* had the maximum BAF values in the north sector (40.10 and 967.04) and South sector (107.16 and 2414.25), respectively. According to the calculated BAF values, although emergent hydrophytes have the maximum ability to accumulate single heavy metal, it has not the maximum capability to accumulate multi HMs.

Table 6 : The values of metal accumulation index (MAI) for studied plant species.

Plant species	Metal accumulation index (MAI)				
	North sector		South sector		Mean
	Summer	Winter	Summer	Winter	
E. crassipes	25.95	19.19	29.74	19.73	23.65
E. stagnina	11.50	15.80	13.43	16.95	14.42
P. australis	27.01	31.39	48.04	38.30	36.19
T. domingensis	20.44	12.14	26.20	17.56	19.09

Obtained BAF values in the present study are more than those reported previously by Ogunkunle *et al*. (2016) and El-Amier (2017), but they are in agreement with Zurayk *et al*. (2001) and Bonanno and Giudice (2010) findings. Generally, the accumulation of the heavy metals varied in this work depending on the plant species and from organ to organ (McLaughlin *et al*., 1999). Moreover, the other factors such as sampling sites, sampling time and meteorology properties can also influence the accumulation of metals by plants (Hofman *et al*., 2013).

Metal accumulation index (MAI)

The MAI values for the selected hydrophytes were summarized in Tables 6. By applying this index to our results for individual species, The MAI was found in the order of *P. australis* > *E. crassipes* > *T. domingensis*>*E. stagnina*. The maximum mean MAI values were found in *P. australis* (36.19) along the Lake during seasonal change. *E. stagnina* has the minimum MAI values in summer (11.50 and 13.43) and winter seasons (15.80 and 16.95) in north and south of the lake, respectively. These results were in accordance with a similar study carried out by Gallon *et al*. (2004), Chandra and Kulshreshtha (2004) and Farrag *et al*. (2013).

Rooted macrophytes such as *P. australis* and *T. domingensis* are generally more influenced by metals in sediment than by those in water, consequently, bioaccumulation is greater than free-floating hydrophytes

(Zwolsman *et al.*, 1993). According to Sawidis *et al.* (1995), Bonanno and Giudice (2010) roots and rhizomes of *P. australis* and *T. domingensis* can accumulate a lot of heavy metals because of the cortex parenchyma with large intercellular air spaces.

Inter-elemental correlations in water, sediment and plants

Inter-relationship of heavy metals in water, sediment and plants of the study area is summarized in table 7. Heavy metals analysis showed that some pairs have significant correlations ($P < 0.01$) between *E. crassipes* and water such as Fe-Co ($r = 0.695$), Co-Fe ($r= 0.430$), Co-Cd ($r=0.428$), Cr-Ni ($r=0.412$) and Pb-Ni ($r=0.468$). Similarly, a strong correlation was also observed in *T. domingensis* and sediment Fe-Ni ($r=0.453$), Ni-Cd ($r=0.566$), Cd-Cd ($r=0.556$) and Co-Cd ($r=0.534$). In tissue of *P. australis* and sediment for Fe-Cd ($r=0.529$) and Ni-Cd ($r=0.430$), while in *E. stagnina* and sediment for Cd-Cd ($r=0.471$), Co-Cr ($r=0.401$) and Cr-Cd ($r=0.403$). A correlation metrics gives us information about heavy metal sources and pathways (Manta *et al.*, 2002). It's obvious that, the weak correlation of heavy metals in sediment and plants can be attributed to the variable concentrations of these metals and different properties of sediment of the area as well as variation in plant uptake (Yang *et al.*, 2011; Naz *et al.*, 2013).

The literature review showed that the significant correlations of heavy metal concentrations between plant, water and sediment indicate that metal accumulation in *P. australis* and *T. domingensis* reflects the temporal fluctuations of elements in water and sediment (Bargagli, 1998; Zakova and Kockova, 1999; Vardanyan and Ingole, 2006).

Conclusion

The metal ions in Idku Lake (Egypt) were analyzed in sediment and water from 12 sites distributed in northern and southern parts during summer and winter seasons. It has been found that Fe was the abundant metal in both samples. The risk index calculations give highly potential risk for Cd in sediments of the lake which is related to different agricultural and industrial wastes. The bioaccumulation of different metals in four selected plant species (namely: *E. crassipes*, *E. stagnina*, *P. australis* and *T. domingensis*) showed different accumulation results of metals based on BAF calculations as it can be used as bioremediators. The

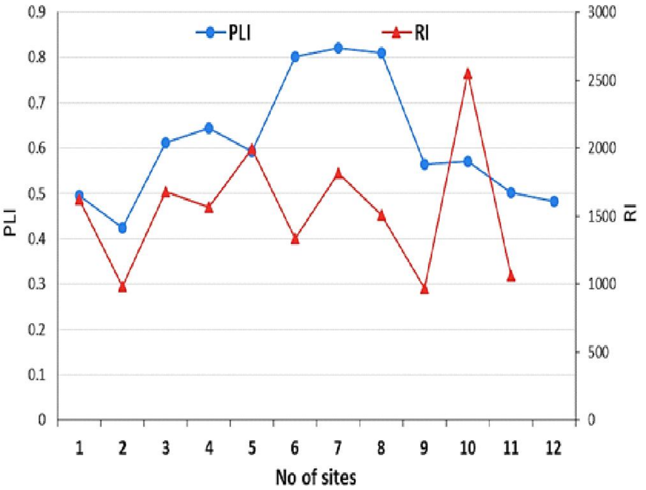

Fig. 2 : Ecological risk index (RI) and pollution load index (PLI) in thesediment of Idku Lake.

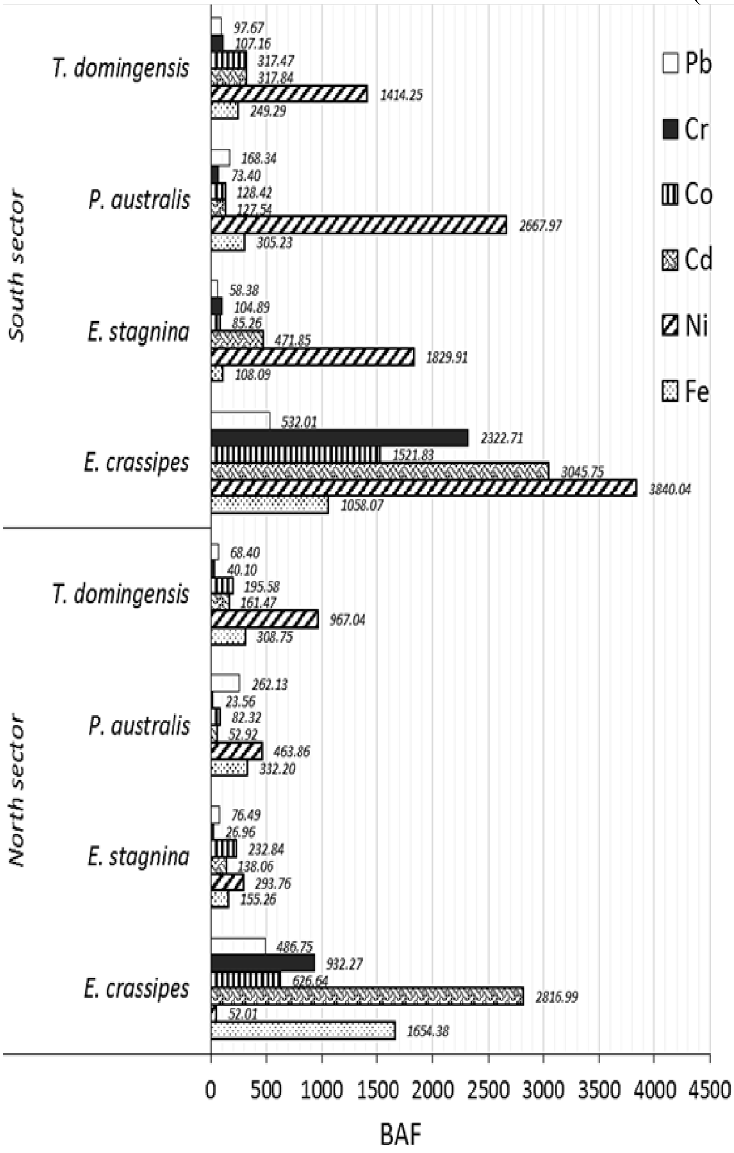

Fig. 3 : Bioaccumulation factor (BAF) of studied aquatic plants in Idku lake.

Table 7 : Pearson correlation coefficient (r-values) between heavy metals concentration of water, sediment and aquatic plant in Idku Lake. The significant values are in the bold letters. *P < 0.05, **P < 0.01

		Water					
		Fe	**Ni**	**Cd**	**Co**	**Cr**	**Pb**
E. crassipes	Fe	0.124	-0.026	0.232	**0.695***	-0.016	0.124
	Ni	0.282	0.101	0.221	-0.471	-0.294	0.086
	Cd	-0.286	0.017	-0.408	**-0.610***	0.109	-0.158
	Co	**0.430***	0.044	**0.428***	-0.331	-0.231	0.068
	Cr	0.193	**0.412***	-0.025	-0.537	-0.573*	0.254
	Pb	0.052	**0.468***	-0.202	-0.273	**-0.587***	0.319
		Sediment					
		Fe	**Ni**	**Cd**	**Co**	**Cr**	**Pb**
E. stagnina	Fe	0.011	-0.119	**-0.548***	-0.04	0.319	-0.153
	Ni	-0.186	-0.223	0.218	0.020	-0.152	0.256
	Cd	-0.076	-0.069	**0.471***	0.001	0.006	0.129
	Co	0.075	-0.031	**-0.447***	-0.050	**0.401***	-0.230
	Cr	-0.118	-0.149	**0.403***	-0.004	0.042	0.156
	Pb	0.106	0.267	0.294	0.037	-0.305	0.055
P. australis	Fe	-0.027	-0.156	**0.529***	-0.031	0.245	-0.092
	Ni	-0.181	-0.212	**0.430**	0.017	-0.121	0.255
	Cd	-0.188	-0.240	0.252	0.012	-0.085	0.246
	Co	-0.190	-0.281	0.068	0.002	0.001	0.204
	Cr	-0.189	-0.244	0.238	0.011	-0.078	0.243
	Pb	0.119	0.053	**-0.510***	-0.039	0.301	-0.155
T. domingensis	Fe	0.108	**0.453***	0.368	0.025	-0.206	-0.019
	Ni	-0.072	0.021	**0.566***	0.037	-0.293	0.212
	Cd	-0.100	-0.038	**0.556***	0.030	-0.231	0.224
	Co	-0.119	-0.076	**0.534***	0.027	-0.203	0.234
	Cr	-0.118	-0.076	0.176	0.043	**-0.443***	0.230
	Pb	-0.182	-0.288	0.094	-0.008	0.078	0.180

application of MAI proofed this and showed different plant efficacies which ordered as follow; *P. australis* > *E. crassipes* > *T. domingensis* > *E. stagnina*. Plants were no longer used as green technologies for removal of serious pollutants as HMs from aquatic bodies.

References

Abdo, M. H. (2005). Physico-chemical characteristics of Abu Za'baal Ponds, Egypt. *Egyptian Journal of Aquatic Research*, **31** : 1-15.

Abdullah, S. M. A., Z. I. F. Rahemo and A. A. Shwani (2007). The inhabitant fishes in Darbandikhan Lake in north of Iraq and methods for developing their culturing. *Egyptian Journal of Aquatic Biology and Fisheries*, **11** : 1-7.

Abida, B. Ramaiah, M. Harikrishna, I. Khan and K. Veena (2009). Heavy metal pollution and chemical profile of Cauvery river water. *E-Journal of Chemistry*, **6** : 47–52.

Alcamo, J., M. Floerke and M. Maerker (2007). Future long-term changes in global water resources driven by socio-economic and climatic changes. *Hydrological Sciences Journal*, **52** : 247-275.

Allen, S. E., H. M. Grimshaw, J. A. Parkinson, C. Quarmby and J. D. Roberts (1974). Chemical Analysis of Ecological Materials. Blackwell Scientific Publications. Osney, Oxford, London.

Altun, O., M. T. Sacan and A. K. Erdem (2009). Quality and heavy metal monitoring in water and sediment samples of the Kucukcekmece Lagoon, Turkey (2002-2003). *Environmental Monitoring and Assessment*, **151** : 345-362.

APHA (1989). *Standard Methods for the Examination of Water and Waste water*, Part 3, Determination of Metals. 17th, American Public Health Association, Washington DC, 164.

APHA (American Public Health Association) (1992). Standard Methods for the Examination of Water and Waste water. Washington, 18th ed. DC. 1.

ATSDR (2008). Draft toxicological profile for cadmium Atlanta: US Department of Health and Human Services, Agency for Toxic Substances and Disease Registry. Available from: http://www.atsdr.cdc.gov/toxprofiles/tp5-p.pdf (Accessed June 2009).

Banat, I. M., E. S. Hassan, M. S. El-Shahawi and A. H. Abu-Hilal (1998). Post-gulf-war assessment of nutrients, heavy metal ions, hydrocarbons, and bacterial pollution levels in the United Arab Emirates coastal waters. *Environment International*, **24** : 109-116.

Bargagli, R. (1998). Trace elements in terrestrial plants. An ecophysiological approach to biomonitoring and biorecovery. Springer, Berlin, 324 pp.

Bonanno, G. and R. L. Giudice (2010). Heavy metal bioaccumulation by the organs of *Phragmites australis* (commonreed) and their potential use as contamination indicators. *Ecological Indicators*, **10** : 639-645.

Boulos, L. (1999-2005). *Flora of Egypt*. Vols. 1, 2, 3, and 4, All Hadara Publishing, Cairo, Egypt.

Canadian Soil Quality Guidelines (CSQG) (2007). Canadian soil quality guidelines (CSQG) for the protection of environmental and human health: Summary tables. Updated September. (2007). In: *Canadian environmental quality guidelines* (1999). Canadian Council of Ministers of the Environment, Winnipeg by Canadian Council of Ministers of the Environment (CCME).

Chandra, P. and K. Kulshreshtha (2004). Chromium accumulation and toxicity in aquatic vascular plants. *Botanical Review*, **70** : 313-327.

El-Alfy, M. A., H. Abd El-Azim and Y. A. El-Amier (2017). Assessment of heavy metal contamination in surface water of Burullus Lagoon, Egypt. *Journal of Scientific Agriculture*, **1** : 233-243.

El-Ameir, Y. A. (2017). Evaluation of heavy metal pollution in Damietta Branch of Nile River, Egypt using metal indices and phyto-accumulators. *Journal of Environmental Sciences*, **46** : 89-102.

El-Serehy, H. A., H. Aboulela, F. Al-Misned, M. Kaiser, K. H. Al-Rasheid and H. Ezz El-Din (2012). Heavy metals contamination of a Mediterranean coastal ecosystem, eastern Nile Delta, Egypt. *Turkish Journal of Fish and Aquatic Sciences*, **12** : 751-760.

EPA (Environmental Protection Agency) (1977). National secondary drinking water regulations. *Federal Register*, **42** : 17143-17147.

EPA (2002). *Environmental Protection Agency*. National Recommended Water Quality Criteria, USA, 822-R-02-047.

Farrag, H. F., Y. M. Al-Sodany and F. G. Otiby (2013). Phytoremediation and accumulation characteristics of heavy metals by some plants in Wadi Alargy-Wetland, Taif-KSA. *World Applied Sciences Journal*, **28** : 644-653.

Gallon, C., C. Munger, S. Premont and P. G. C. Campbell (2004). Hydroponic study of aluminum accumulation by aquatic plants: effect of fluoride and pH. *Water Air Soil Pollution*, **153** : 135-155.

Gohar, M. A. (1998). Factors affecting the precipitation and dissolution of some chemical elements in River Nile at Damietta branch. *M.Sc. Thesis* Faculty of Science, Menofia University, Egypt.

Hakanson, L. (1980). An ecological risk index for aquatic pollution control; a sedimentological approach. *Water Research*, **14** : 975-1001.

Hassouna, A. F. A. (1989). Some analytical study on sediments on Lake Nasser, River Nile and Aswan Dam zone reservoir. MSc. Thesis, Faculty of Science, Al Azhar University, Cairo, Egypt.

Hofman, J., I. Stokkaer, L. Snauwaert and R. Samson (2013). Spatial distribution assessment of particulate matter in an urban street canyon using biomagnetic leaf monitoring of tree crown deposited particles. *Environmental Pollution*, **183** : 123-132.

Hu, Y., D. Wang, L. Wei, X. Zhang and B. Song (2014). Bioaccumulation of heavy metals in plant leaves from Yan'an city of the Loess Plateau, China. *Ecotoxicology and Environmental Safety*, **110** : 82-88.

Jaishankar, M., T. Tseten, N. Anbalagan, B. B. Mathew and K. N. Beeregowda (2014). Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary Toxicology*, **7** : 60-72.

Jaishankar, M., T. Tseten, N. Anbalagan, B. B. Mathew and K. N. Beeregowda (2014). Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary Toxicology*, **7** : 60–72.

Jickells, T. D. and A. H. Knap (1984). The distribution and geochemistry of some trace metals in the Burmuda coastal environment. *Estuarine, Coastal and Shelf Science*, **18** : 245–262.

Kabata-Pendias, A. and H. Pendias (2001). *Trace elements in soils and plants*, third ed., CRC, New York.

Kadukin, A. I., V. V. Krasintseva and G. I. Romanova (1998). Accumulation of Fe, Mn, Zn, Cu and Cr in Some Aquatic Plants. *Hydrobiological Journal*, **18** : 79-82.

Kesler, S. E. and A. C. Simon (2015). Mineral Resources, Economics and the Environment. Cambridge University Press, Cambridge CB2 8BS, United Kingdom.

Liu, Y-J, Y-G Zhu and H. Ding (2007). Lead and cadmium in leaves of deciduous trees in Beijing, China: development of a metal accumulation index (MAI). *Environmental Pollution*, **145** : 387-390.

Loague, K. and D. L. Corwin (2005). Point and non-point source pollution. Encyclopedia of hydrological sciences. Edited by M G Anderson. *John Wiley & Sons*, Ltd.: 1427-1439.

Ma, L. Q., K. M. Komar, C. Tu, W. Zhang, W. Y. Cai and E. D. Kennelley (2001). A. fern that hyperaccumulates arsenic. *Nature*, **409** : 579-585.

Manta, D. S. M. Angelone, A. Bellanca, R. Neri and M. Sprovieri (2002). Heavy metals in urban soils: a case study from the city of Palermo (Sicily), Italy. *Science of the Total Environment*, **300** : 229–243.

Martínez-López, J., M. F. Carreño, J. Palazón-Ferrando, A. J. Martínez-Fernández and M. A. Esteve (2014). Remote sensing of plant communities as a tool for assessing the condition of semiarid Mediterranean saline wetlands in agricultural catchments. *International Journal of Applied Earth Observation and Geoinformation*, **26** : 193-204.

McGrath, S. P. (1995). Nickel. In : *Heavy Metals in Soils* (2^{nd} edn.) (ed. B. J. Alloway). London: Blackie Academic & Professional.

McLaughlin, M. J., D. R. Parker and J. M. Clark (1999). Metals and micronutrients food safety issues. *Field Crops Research*, **60** : 143–163.

Mireles, A., C. Solis, E. Andrade, M. Lagunas-Solar and R. G. Flocchin (2004). Heavy metal accumulation in plants and soil irrigated with waste water from Mexico City. *Nuclear*

Instruments and Methods in Physics Research Section B, **219**: 187-190.

Mondol, M. N., A. S. Chamon, B. Faiz and S. F. Elahi (2011). Seasonal variation of heavy metal concentrations in water and plant samples around Tejgaon industrial area of Bangladesh. *Journal of Bangladesh Academy of Sciences*, **35** : 19–41.

Monfared, S. H., M. Matinizadeh, A. Shirvany, G. Z. Amiri, R. M. Fard and F. Rostami (2013). Accumulation of heavy metal in *Platanus orientalis, Robinia pseudoacacia* and *Fraxinus rotundifolia*. *Journal of Forestry Research*, **24** : 391–395.

Naz, A., S. Khan, M. Qasim, S. Khalid, S. Muhammad and M. Tariq (2013). Metals toxicity and its bioaccumulation in purslane seedlings grown in controlled environment. *Natural Science*, **5** : 573–579.

Obodai, E. A., L. K. Boamponsem, C. K. Adokoh, D. K. Essumang, B. O. Villawoe, D. W. Aheto and J. S. Debrah (2011). Concentrations of heavy metals in two Ghanaian Lagoons. *Archives of Applied Science Research*, **3** : 177-187.

Obodai, E. A., L. K. Boamponsem, C. K. Adokoh, D. K. Essumang, B. O. Villawoe, D. W. Aheto and J. S. Debrah (2011). Concentrations of heavy metals in two Ghanaian Lagoons. *Archives of Applied Science Research*, **3** : 177-187.

Ogunkunle, C. O., K. Mustapha, S. Oyedeji and P. O. Fatoba (2016). Assessment of metallic pollution status of surface water and aquatic macrophytes of earthen dams in Ilorin, north-central of Nigeria as indicators of environmental health. *Journal of King Saud University-Science*, **28** : 324-331.

Oregioni, B. and S. R. Aston (1984). The Determination of Selected Trace Metals in Marine Sediments by Flameless/ Flam-Atomic Absorption Spectrophotometry. IAEA Monaco Laboratory Internal Report.

Padmavathiamma, P. K. and L.Y. Li (2007). Phytoremediation technology: hyper-accumulation metals in plants. *Water Air Soil Pollution*, **184** : 105-126.

Penga, K., C. Luo, L. Lou, X. Li and Z. Shen (2008). Bioaccumulation of heavy metals by the aquatic plants *Potamogeton pectinatus* L. and *Potamogeton malaianus* Miq. and their potential use for contamination indicators and in waste water treatment. *Science of the Total Environment*, **392** : 22-29.

Pérez-Ruzafa, A., C. Marcos, I. Pérez-Ruzafa and M. Pérez-Marcos (2010). Coastal lagoons: transitional ecosystems between transitional and coastal waters. *Journal of Coastal Conservation*. doi: 10.1007/s11852-010-0095-2.

Qunfang, Z., Z. Jianbin, F. Jianjie, S. Jianbo and J. Guibin (2008). Biomonitoring : An appealing tool for assessment of metal pollution in the aquatic ecosystem. *Analytica Chimica Acta*, **606** : 135–150.

Saeed, M. S. and I. M. Shaker (2008). Assessment of heavy metals pollution in water and sediments and their effect on *Oreochromis niloticus* in the northern Delta Lakes, Egypt, 8th Int. Symposium on Tilapia in Aquaculture, 475–490.

Saeed, S. M. (2013). Impact of environmental parameters on fish condition and quality in Lake Edku, Egypt. *Egyptian Journal of Aquatic Biology and Fisheries*, **17** : 101-112.

Sawidis, T., M. K. Chettri, G. A. Zachariadis and J. A. Stratis (1995). Heavy metals in aquatic plants and sediments from water systems in Macedonia, Greece. *Ecotoxicology and Environmental Safety*, **32** : 73–80.

Schindler, D. W., K. A. Kidd, D. C. G. Muir and W. L. Lockhart (1995). The effects of ecosystem characteristics on contaminant distribution in northern freshwater lakes. *Science of the Total Environment*, **160/161** : 1–17.

Sood, A., P. L. Uniyal, R. Prasanna and A. S. Ahluwalia (2012). Phytoremediation Potential of Aquatic Macrophyte, Azolla. *AMBIO*, **41** : 122-137.

Stankovic, S., M. Jovic, A.R. Stankovicand, L. Katsikas (2012). Heavy Metals in Seafood Mussels. Risk for Human Health. In: E. Lichthouse, J. Schwarzbauer and D. Robert (eds.), *Environmental Chemistry for a Sustainable World, Nanotechnology and Health Risk*, Springer, Dordrecht, 311-373.

Täckholm, V. (1974). *Students Flora of Egypt*. 2nd ed. Cairo University Press, Egypt.

Taha, A. A., A. S. El-Mahmoudi and I. M. El-Haddad (2004). Pollution sources and related environmental impacts in the new communities' southeast Nile delta, Egypt. *Emirates Journal for Engineering Research*, **9** : 35-49.

Tomilson, D. C., D. J. Wilson, C. R. Harris and D. W. Jeffrey (1980). Problem in assessment of heavy metals in estuaries and the formation of pollution index. *Helgol Wiss Meeresunlter*, **33** : 566-575.

Turer, D., J. B. Maynard and J. J. Sansalone (2001). Heavy metal contamination in soils of urban highways comparison between runoff and soil concentrations at Cincinnati. *Water, Air and Pollution*, **132** : 293-314.

Ugulu, I., Y. Dogan, S. Baslar and O. Varol (2012). Biomonitoring of trace element accumulation in plants growing at Murat Mountain. *International Journal of Environmental Science and Technology*, **9** : 527-534.

Vardanyan, L. G. and S. Ingole Baban (2006). Studies on heavy metal accumulation in aquatic macrophytes from Sevan (Armenia) and Carambolim (India) Lake Systems. *Environment International*, **32** : 208–218.

Vazquez, J. F. G., L. G. Aguilera and V. K. Sharma (1994). Metals in sediments of San Andres Lagoon, Tamaulipas, Mexico. *Bulletin of Environmental Contamination and Toxicology*, **52** : 382 -387.

Venkatesha, R. K., R. K.Somashekar and K. L. Prakash (2013). Biomonitoring of metals in freshwater macrophytes and benthic organisms. *International Journal of Innovative Research in Science, Engineering and Technology*, **2** : 4661-4670.

Yahya, A. N., S. K. Mohamed and A. G. Mohamed (2018). Environmental Pollution by Heavy Metals in the Aquatic Ecosystems of Egypt. *Open Access Journal of Toxicology*, **3** : 1-9.

Yang, Z., W. Lu, Y. Long, X. Bao and Q. Yang (2011). Assessment of heavy metals contamination in urban topsoil from Changchun City, China. *Journal of Geochemical Exploration*, **108** : 27–38.

Yoon, J., X. Cao, Q. Zhou and L. Q. Ma (2006). Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site. *Science of the Total Environment*, **368** : 456-464.

Zaghloul, H. K. (2001). Usage of zinc and calcium in inhibiting the toxic effect of copper on the African cat fish *Clarias gariepinus*. *Journal of the Egyptian German Society of Zoology*, **35** : 99-120.

Zakova, Z. and E. Kockova (1999). Biomonitoring and assessment of heavy metal contamination of streams and reservoirs in the Dyje/Thaya river basin, Czech Republic. *Water Science & Technology*, **39** : 225–232.

Zhu, W., B. Bian and L. Li (2008). Heavy metal contamination of road-deposited sediments in a medium size city of China. *Environmental Monitoring and Assessment*, **147** : 171-181.

Zurayk, R., B. Sukkariah and R. Baalbaki (2001). Common hydrophytes as bioindicators of nickel, chromium and cadmium pollution, *Water*, *Air&Soil Pollution*, **127** : 373-388.

Zwolsman, J. J. G., G. W. Berger and G. T. M. Van Eck (1993). Sediment accumulation rates, historical input, post depositional mobility and retention of major elements and trace metals in salt marsh sediments of the Scheldt estuary, SW Netherlands. *Marine Chemistry*, **4** : 73–94.