

Phytoremediation Potentiality of Aquatic Macrophytes in Heavy Metal Contaminated Water of El-Temsah Lake, Ismailia, Egypt

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Abstract: Six hydrophytes were examined for their ability to remove heavy metals from contaminated water of El-Temsah Lake. Six heavy metals, Cd, Co, Cu, Ni, Pb, Zn were assessed in water, sediments and the various plant organs of the selected plants using atomic absorption. Several physicochemical parameters, from five sampling sites in El-Temsah Lake were studied during 2010-2011. The amount of heavy metals in water, sediments and plant organs were used to evaluate the concentration factor (CF), transfer factor (TF) and enrichment coefficient (EC). The concentration and toxicity status recorded in the studied macrophytes, the six metals are arranged in the following descending order: Zn > Pb > Cd > Cu > Ni > Co. Compared with the standard, normal and critical toxicity range in plants, the scored values of all studied six metals fall in the critical range. CF values ranged between 0.07 in *T. domingensis* and 1172.8 *E. crassipes*, while TF values were 0.16 and 4.83 in case of *L. gibba* and *P. australis* respectively and *C. demersum* recorded the highest EC values in roots, stems and leaves. The effective wide range of tolerance of the selected plants to all the studied metals suggests the use of these plants for large scale removal of heavy metals from waste water and natural basins.

Key words: Aquatic Macrophytes • El-Temsah Lake • Biomonitoring • Phytoremediation • Heavy Metals (Co, Cd, Cu, Ni, Pb, Zn) • Water Pollution

INTRODUCTION

Overpopulation, industrialization, rapid urbanization, overuse of pesticides, detergent and agricultural chemicals, liquid and solid waste products and discharge of municipal wastes resulted in heavy metal pollution of natural water resources [1]. The increased loading of heavy metals in the aquatic ecosystems furnished an imbalance state and threatened the health of the native biota growing under such abnormal habitat conditions, consequently, accumulation of high concentration of heavy metals such as Cd, Cu, Co, Cr, Hg, Ni, Pb and Zn has been recorded which in turn are being assimilated and transferred within food chains by the processes of bioaccumulation and biomagnification [2-4].

As a result of the aforementioned human impacts to the aquatic environment thoughts have been directed towards the innovation of new environmental friendly

technology for the heavy metal removal from the environment, phytoremediation is an integrated multidisciplinary approach to the cleanup of contaminated soils and water using plants [5, 6]. Aquatic macrophytes among those plants that efficiently manipulated in the absorption, accumulation and removal of heavy metals from the surrounding aquatic habitat through phytoremediation technology. Dozens of research papers were published on the use of aquatic macrophytes in the phytoremediation of the aquatic habitat from different kinds of heavy metals. The use of *Eichhornia crassipes* was reported by several authors [7-10] documented for the use of *Myriophyllum spicatum* in the absorption and accumulation of several heavy metals. The utilization of *Phragmites australis*, *Lemna gibba*, *Typha domingensis* and *Ceratophyllum demersum* in the phytoremediation of the aquatic habitats was also reported by several authors [11-14].

In the last three decades the aquatic ecosystem of El-Temsah Lake recorded hazardous levels of pollutants of various forms, heavy metals concentrations in the water sediments and marine fauna was reported by [15-18]. While, pesticides and polycyclic and aromatic hydrocarbons were investigated by [19, 20]. More detailed information about the effective role of the aquatic vegetation in the mitigation of heavy metal pollution in the water and sediments of EL-Temsah Lake is still required, this is due to the important geographical, biological, economical position of the lake and the continuous and rapid change in this area. Additionally, the occurrence of El-Temsah Lake in the midway of the Suez Canal which is considered as a transitional zone that connects between two basically different basins; Indopacific-Red Sea basin and the Atlanto-Mediterranean basin which in turn influenced the fauna and flora [21].

Two main objectives are addressed in the present study; the first is to assess the concentration of the heavy metals; Cd, Co, Cu, Ni, Pb and Zn in the water and sediments of El-Temsah Lake along with six native aquatic macrophytes species; *Ceratophyllum demersum*, *Myriophyllum spicatum*, *Eichornia crassipes*, *Lemna gibba*, *Phragmites australis* and *Typha domingensis*.

The second objective is to investigate the phytoremediation potentiality of these aquatic macrophytes to the selected heavy metals and the vertical translocation of these metals from water, sediments into root system and subsequently the shoot system of the inspected plant species.

MATERIALS AND METHODS

Study Area: El-Temsah Lake is located near the midpoint of the Suez Canal, at point 80 Km south of Port Said Governorate. Its formation is due to a depression in a fault trough covered with Nile Delta Sediments [22]. The total surface area of the lake is about 15 Km², it extends between 30°32' and 30°36' N and 32°16' and 32°21' E (Fig. 1) and the detailed characteristics of the lake in Table 1.

The lake has four islands, it is the major source for fishes, crustaceans, bivalves and shellfish largely consumed by local populations, additionally, the northern and western boundaries shores of the lake are rapidly developed for tourism purpose, aquatic sports and recreation activities.

The rapidly growing human activities in the last 35 years around El-Temsah Lake such as ship building and maintenance, municipal waste water dumping off and agricultural drainage loading in the lake have greatly increased the eutrophication and pollution status of the lake [23, 24] and consequently these conditions threatened the health of the lake, interfere with its recreational purpose, lake richness and diversity of indigenous fish, phytoplankton, zooplankton, plants and animal population.

Additionally, the specific water quality of the lake affects the essential role of the Suez Canal as a major waterway on the migration of the organisms (Lessipsian and Antileissipsian) migration.

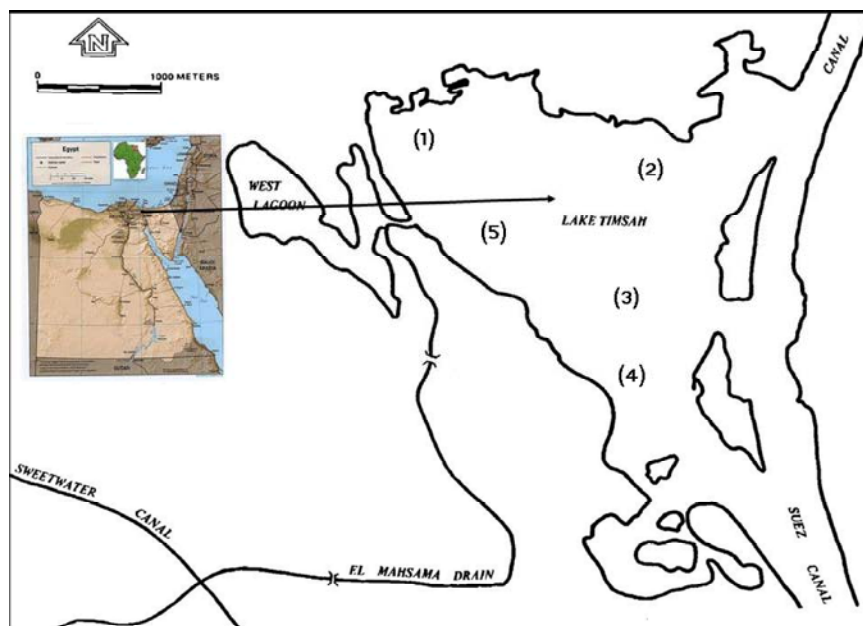


Fig. 1: Location map of El-Temsah Lake along with the sampling stations.

Table 1: General characteristics of El-Temsah Lake

Genesis	Tectoncially as a part of "Clysmic Gulf"
Location	Middle of Suez Canal at a point 80 km Ismailia.
Latitude	30°32' and 30°36' North Latitude
Longitude	32°16' and 32°21' East Longitude
Lake type	Hydrographic
Water sources	Marine water from Suez Canal Partially treated domestic sewage, Agricultural drainage, Industrial drainage.
Surface area	15 Km ²
Water volume	90,000,000 m ³
Trophic Status	Eutrophic Lake
Shape	Triangular
Maximum depth	13 m
Average depth	3 m
Number of islets	4
Water Current	20 Cm / Sec.
Plankton	Phytoplankton: 153 Species Zooplankton: 120 Species
Flora	Terrestrial Plants: 25 Species Aquatic Plants: 20 Species
Fauna	Fishes: 26 Species Birds: 40 Species Mammals: 13 Species Reptiles & Amphibians: 12 Species
Significance	Lessepsian migration of Biota, Recreational and Fisheries.

Table 2: Climatological data of El-Temsah Lake

Parameter								
Temperature				Relative Humidity (%)	Rain Fall (mm)	Daily Mean Evaporation (mm)	Fog	Win Speed Km/Hr
Month	Max	Min	Mean					
Jan	20.4	8.1	14.2	70	4.4	4.7	3.2	3.5
Feb	21.7	9.1	15.4	68	4.7	5.4	3.4	4.0
Mar	23.9	11.0	17.4	60	3.0	6.8	3.4	4.7
Apr	27.6	13.6	20.6	41	1.1	7.0	3.7	4.1
May	32.1	17.3	24.7	58	0.8	9.8	3.0	3.8
Jun	34.8	20.2	27.5	63	0.0	9.7	1.3	3.2
Jul	36.4	22.2	29.3	68	0.0	9.3	1.1	3.8
Aug	36.5	22.5	29.5	68	0.0	8.6	1.3	3.5
Sep	33.9	20.7	27.3	69	0.0	7.5	1.4	3.1
Oct	30.7	17.8	24.2	70	2.2	6.4	2.1	3.2
Nov	26.6	13.9	20.2	74	4.7	4.7	2.9	2.6
Dec	21.5	10.0	15.8	78	8.5	3.8	3.6	3.2
Tot. Ann					29.4	2.55		
Mean Ann.	28.8			67		7.0		3.6

Climatic Records: The climatic records of the lake are shown in Table (2) [25], Based on that climatic records and according to [26], the eastern part of the Nile Delta where the study area is located, lies in the arid-hyper arid region.

Water Resources: Several water resources enrich the lake with different kinds of water viz saline water from the Suez Canal, freshwater from Ismailia Sweet freshwater canal, partially treated wastewater through several agricultural, industrial, domestic sewage drains such as Al-Mahsama Drain, Al-Wadi Drain, Al-Bahtimi Drain, Al-Dabiaia Drain and Al-forsan Drain [27, 28].

Field Work: Sampling occurred during (spring 2010-winter 2011), five sampling stations were selected to cover the different microhabitats (Fig. 1).

Plant Sampling: Six dominant aquatic macrophytes species were selected and identified according to [29]. Two of them were submerged species; *Ceratophyllum demersum* (coontail) and *Myriophyllum spicatum* (parrot feather), two floating species *Eicchornia crassipes* (water hyacinth) and *Lemna gibba* (duckweed) and two emergent species; *Phragmites australis* (common reed) and *Typha domingensis* (cattail). Only healthy aquatic macrophytes individuals were selected in triplets at

the population level for estimating the potential loading and the toxicity status induced by six heavy metals [6, 30, 31 & 32]. Individual plants were carefully collected, washed with lake water to remove periphyton, sediment particles and other debris. The plants were immediately transferred to the laboratory in clean plastic bags, sorted into roots, stems and leaves, oven dried 80 – 90°C for 48 h, grounded into very fine powders, stored in glass bottles and labeled for further analysis.

Sediments Sampling: Three samples of bottom sediments of El-Temsah Lake were collected at each of the five sampling stations, transferred to the laboratory in clean plastic bags, air dried, sieved by 2 mm sieve, mixed to form one composite sample representing each station and stored for analysis.

Water Sampling: Five water parameters were measured (*in situ*) for the lake's water, in the five sampling stations, these parameters were: pH, Dissolved oxygen (DO%), electric conductivity (E.C) ($\mu\text{mhos/cm}$), salinity was calculated from E.C. as a total soluble salts (TSS) and Water transparency was estimated using white enameled Secchi disc according to [33, 34].

Chemical Analysis of Plants, Water and Sediments

Samples: For the estimation of nutrients and chlorophyll *a*, water samples were collected in triplicate from the previously selected five sampling stations in PVC Nansen bottles (1.5 L). Water samples were filtered through GF/C filters and the filtrates were used for the determination of the nutrients concentrations (phosphate, nitrate, nitrite and ammonia) according to the methods described by [35, 36]. For the estimation of chlorophyll *a*, 500 ml of lake water were passed through a 0.45 μm membrane filters, then extracted with 90% acetone and measured spectrophotometrically at the wavelengths 630, 645, 665 and 750 nm [35, 36].

The samples of plant organs, water and sediments were analyzed for the detection of heavy metals (Cd, Co, Cu, Ni, Pb, Zn). Exactly, one gram of dry powder of each sample was weighed and digested using the following digestion mixture (Conc. HNO_3 , H_2SO_4 , H_2O_2) in the following ratio (1:3:3). The metal concentration in plant material, water and sediments were measured by atomic absorption (Model, PYE UNICAM SP9, England) and expressed as dry weight, mg l^{-1} and mg kg^{-1} respectively [37].

Data analysis: The toxicity status was determined in plant and soil samples by comparing their heavy metal concentration against the standard critical concentration ranges [38, 39].

The concentration factor (CF) was calculated for all the investigated plants [40]. Transfer factor (TF), Enrichment coefficients (EC) were calculated according to [41] and were expressed by three different ratios; Enrichment coefficient of root (ECR): concentration of element in root/concentration of element in sediments, Enrichment coefficient of stem (ECS): concentration of element in stem / concentration of element in sediment and Enrichment coefficient of leaf (ECL): concentration of element in leaf / concentration of element in sediment.

RESULTS

El-Temsah Lake represents a unique aquatic ecosystem due to the different types of water input; main saline water source from the Suez Canal, clean fresh water from Ismailia sweet water canal and brackish water from a series of drains. At least, there are three major sources responsible for the heavy metal contamination in El-Temsah Lake namely; agricultural drainage, industrial drainage, municipal (sewage) effluent. Heavy metals are considered the most hazardous contaminant in the environment due to their persistence and accumulation in water, sediments and in tissues of the living organisms; this is by bioconcentration and biomagnification [2, 3, 4].

Physicochemical Analysis of Water: The chemical analysis of water samples in the studied five stations along with the nutrient status is represented in Table 3. From that table it is clear that the pH of El-Temsah Lake lies in the alkaline side in all the studied stations, the lowest pH value was recorded in station 5 (near the middle of the lake) as 8.2 while the highest pH value was 8.8 in station 1.

Regarding DO%, it is clear that El-Temsah Lake is well aerated and contains moderate oxygenation level, the lowest value for DO% was 8.2% in station 5 while the highest value of DO% was 12.4% and recorded in station 1. The lowest value for T.S.S was 30.1 mg/l recorded in station 5, whereas the highest value was 37.6 mg/l and recorded in station 1.

Table 3: Physicochemical parameters and nutrients concentrations in the water samples collected from the five stations at El-Temsah Lake during spring 2011 - summer 2011

Station Parameter	1	2	3	4	5
pH	8.8	8.4	8.6	8.7	8.2
DO% mg/l	12.4	11.8	11.6	9.4	8.2
E.C. mS/l	58.8	57.4	53.6	50.4	46.8
T.S.S mg/l	37.6	36.7	34.3	32.3	30.1
Chlorophyll <i>a</i> $\mu\text{g/l}$	30.1	33.1	36.2	48.4	56.5
Transparency (m)	3.8	2.9	2.5	1.6	1.2
Nitrite Nitrogen mg/l	275.4	258.6	221.3	215.2	228.1
Nitrate Nitrogen mg/l	1.5	1.3	1.2	0.8	1.1
Ammonium Nitrogen mg/l	2.1	2.8	3.5	2.3	2.5
Total Phosphorous $\mu\text{g/l}$	550.1	475.3	482.8	482.8	398.4

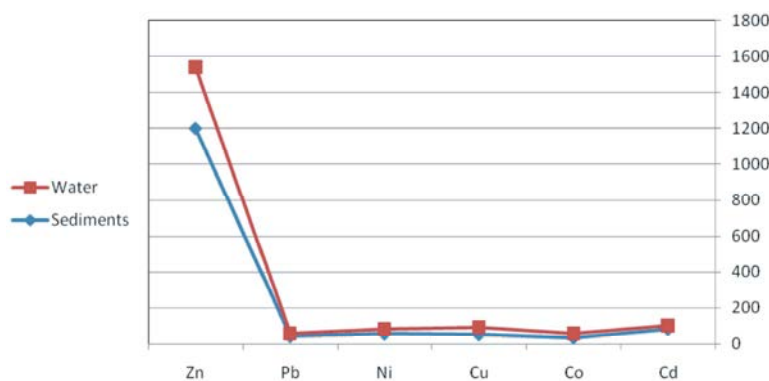


Fig. 2: Mean concentration (ppm) of six heavy metals in water and sediment samples of El-Temsah Lake.

The high productivity rate of El-Temsah Lake was indicated by the high phytoplankton biomass (Chlorophyll *a*) content. The lowest value of Chlorophyll *a* content was scored in station 1 as 30.1 $\mu\text{g/l}$, while the highest value was 56.5 $\mu\text{g/l}$ in station 5.

Regarding the estimated nutrients in the five samples of El-Temsah Lake it has recorded higher values greatly exceeded the normal concentrations. The values of nitrite nitrogen ranged between 215.2 mg/l in station 4 and 275.4 mg/l in station 1. Nitrate nitrogen concentrations ranged between 0.8 mg/l in station 4 and 1.5 mg/l in station 1. The concentrations of ammonium nitrogen were 2.1 mg/l in station 1 and 3.5 mg/l in station 3. Finally, the total phosphorous concentrations were very high and ranged between 398.4 $\mu\text{g/l}$ in station 5 and 550.1 $\mu\text{g/l}$ in station 1.

Water and Sediments: The results of the present study focused on the assessment of current status of the heavy metal pollution (Cd, Co, Cu, Ni, Pb, Zn) in El-Temsah Lake water, bottom sediments and the uptake, translocation and accumulation potentialities by six native aquatic macrophytes naturally growing and widespread in the lake, *Ceratophyllum demersum*, *Myriophyllum spicatum*, *Eichhornia crassipes*, *Lemna gibba*, *Phragmites australis* and *Typha domingensis*.

The investigated heavy metals showed higher concentrations in the lake's bottom sediments than the lake's water. Zinc recorded (340.16 mg/l^{-1}) which is the highest concentrations among the investigated heavy metals in the water of El-Temsah Lake. Similarly, the Lake's sediments followed the same pattern and scored 1200.5 mg/l^{-1} . The value of the ratio between the concentration of Zn in water and sediments was 3.52. Cadmium also followed the same trend of Zn and recorded 82.62 mg/l^{-1} and 20.91 mg/l^{-1} in the sediments and water respectively, whereas, the ratio between them was 2.1. With respect to Pb concentration in the sediments it reached 42.18 mg/l^{-1} and 18.27 mg/l^{-1} in water with a ratio of 2.31.

Also the mean value of the total heavy metal content in the sediments recorded higher value than that of water 244.18 mg/l^{-1} and 78.8 mg/l^{-1} respectively (Fig. 2).

Aquatic Macrophytes: Applying the unilateral F-test on the accumulation of each metal separately in roots, stems and leaves of the investigated aquatic macrophytes, it is clearly obvious that the accumulation of heavy metals is more significant for Cd followed by Zn, Pb, Co, Cu and Ni (Table, 4).

Table 4: The results of unilateral F-Test for the accumulation of the individual heavy metal in roots, stems and leaves of the investigated aquatic macrophytes

Metal	Cd	Co	Cu	Ni	Pb	Zn
F-Value	3.9	1.2	0.43	0.43	1.6	1.7

Table 5: The mean values of the heavy metals concentration (ppm) in the studied aquatic macrophytes of El-Temsah Lake.

	My sp	Cer dem	Eich cra	Lem gib	Phra aus	Typ dom	Mean
Cd	1.79	2.35	1.8	1.34	3.21	1.38	1.98
Co	17.35	23.5	32.5	9	43.1	42	27.91
Cu	74.97	96.3	53.8	36.4	129.21	153.2	90.65
Ni	30.63	48.09	125.3	25.23	151.6	91.55	78.73
Pb	163.34	208.71	37.26	104	42.4	23.87	96.60
Zn	903.3	1172.8	1677	531.5	843.2	862.4	998.37
Mean	198.56	258.62	321.28	117.91	202.12	195.73	
SD	350.22	453.84	665.441	205.880	319.128	331.075	

My sp= *Myriophyllum spicatum*, Cer dem= *Ceratophyllum demersum*, Eich cra= *Eichhornia crassipes*, Lem gib= *Lemna gibba*, Phra aus= *Phragmites australis* and Typ dom= *Typha domingensis*.

The mean values of the six investigated heavy metals in the six selected aquatic macrophytes are presented in Table 5. The mean concentration of values of the heavy metals in these plants decreased according to the following sequence: Zn > Pb > Cu > Ni > Co > Cd. Regarding the mean values of the heavy metal concentrations among the studied plants it showed the following pattern *Eichhornia crassipes* > *Ceratophyllum demersum* > *Phragmites australis* > *Myriophyllum spicatum* > *Typha domingensis* > *Lemna gibba*.

The highest mean heavy metal concentration value was scored by *Eichhornia crassipes* (321.28 ppm), *Ceratophyllum demersum* (258.62 ppm), *Phragmites australis* (202.12 ppm), *Myriophyllum spicatum* (198.56 ppm), *Typha domingensis* (195.73 ppm) and *Lemna gibba* (117.91) (Table, 5). Among all the studied heavy metals the highest metal concentration in the plant tissues was recorded by Zn (1172.8 ppm) in *Ceratophyllum demersum*, while the lowest value was (1.34 ppm) for Cd in *Lemna gibba*.

Variation of individual metal also recorded among the studied species, the content of Cd ranged from 1.34 to 3.21 ppm in *Lemna gibba* and *Phragmites australis* respectively. The cobalt content recorded lowest value of 9 ppm in *Lemna gibba* and the highest value 43.1 ppm in case of *Phragmites austrails*. In the same way, the content of copper ranged from 36.4 to 153.2 ppm in case of *Lemna gibba* and *Typha domingensis* respectively. The content of Nickel fluctuates from 25.23 ppm in *Lemna gibba* to 151.6 ppm in *Phragmites austrails*. Additionally, the lowest concentration of Pb was registered in *Typha domingensis* 23.87 ppm, while the highest concentration of the same metal was observed in *Ceratophyllum demersum* 208.71 ppm. Finally, the minimum concentration

of Zn was recorded in *Lemna gibba* 531.5 ppm, while the maximum concentration was recorded in *Ceratophyllum demersum* 1172.8 ppm (Table, 5).

The variation in the accumulation patterns of the investigated heavy metals in the different organs of the studied aquatic macrophytes was also observed and reported (Table, 6). The heavy metal content in the root system of the six studied aquatic macrophytes macrophytes is characterized by high concentration of Zn (632.15 ppm) in *Ceratophyllum demersum* and low value of Cd (0.56 ppm) in case of *Typha domingensis*. Similarly, the mean concentration of heavy metal in stems of these aquatic macrophytes varied considerably from species to another, the highest concentration of Co and Ni were recorded in the stems of *Phragmites australis* 0.86 and 49.3 ppm respectively. Furthermore, the high concentration of Pb and Zn were 78.4 and 580.2 ppm and were recorded in the stems of *Ceratophyllum demersum* and *Eichhornia crassipes* respectively. With respect to, the mean concentration of the six heavy metals in the leaves of the studied species, it showed also clear variation, the leaves of *Typha domingensis* contained the highest concentration of Co and Cu as 13.8 and 52.5 ppm respectively, while that of *Phragmites australis* accumulated the highest content of Cd and Ni 0.75 and 50.2 ppm respectively. On the other hand, the high concentration of Pb and Zn were 78.4 and 492.3 ppm in the leaves of *Ceratophyllum demersum* and *Eichhornia crassipes* respectively (Table, 6).

Accumulation of Heavy Metals in Aquatic Macrophytes:

The assessment of heavy metals (Cd, Co, Cu, Ni, Pb, Zn) was conducted in six native aquatic macrophytes of El-Temsah Lake, the standard, normal and critical toxicity

Table 6: Heavy metal concentrations in roots, stems and leaves of the studied aquatic macrophytes in El-Temsah Lake

		Cd	Co	Cu	Ni	Pb	Zn	Total
<i>Myriophyllum spicatum</i>	Root	0.86	8.06	32.35	18.31	79.41	416.5	555.5
	Stem	0.72	6.11	26.42	9.16	62.81	371.4	476.6
	Leaf	0.21	3.18	16.2	3.16	21.12	115.4	159.3
	Total	1.79	17.35	74.97	30.63	163.34	903.3	1191.4
<i>Ceratophyllum demersum</i>	Root	0.92	12.1	44.1	23.14	96.12	632.15	808.5
	Stem	0.81	9.3	38.6	16.8	78.4	422.5	566.4
	Leaf	0.62	2.1	13.6	8.15	34.19	118.15	176.8
	Total	2.35	23.5	96.3	48.09	208.71	1172.8	1551.8
<i>Eicchornia crassipes</i>	Root	0.8	11.5	22.5	48.7	16.8	604.5	704.8
	Stem	0.48	8.4	16.8	36.2	9.16	580.2	651.2
	Leaf	0.52	12.6	14.5	40.4	11.3	492.3	571.6
	Total	1.8	32.5	53.8	125.3	37.26	1677	1927.7
<i>Lemna gibba</i>	Root	0.62	4.6	16.8	14.31	52.1	252.4	340.8
	Stem	0.56	3.1	11.4	8.52	38.4	186.4	248.4
	Leaf	0.16	1.3	8.2	2.4	13.5	92.7	118.3
	Total	1.34	9	36.4	25.23	104	531.5	707.5
<i>Phragmites australis</i>	Root	1.6	18.4	48.61	52.1	18.2	69.4	208.3
	Stem	0.86	11.6	36.4	49.3	11.4	438.1	547.7
	Leaf	0.75	13.1	44.2	50.2	12.8	335.7	456.8
	Total	3.21	43.1	129.21	151.6	42.4	843.2	1212.7
<i>Typha domingensis</i>	Root	0.56	16.5	52.6	33.7	9.35	362.6	475.3
	Stem	0.38	11.7	48.1	24.65	6.42	282.5	373.8
	Leaf	0.44	13.8	52.5	33.2	8.1	217.3	325.3
	Total	1.38	42	153.2	91.55	23.87	862.4	1174.4

Table 7: Ranges of heavy metals contents and toxicity status in the investigated plant species, compared with normal and critical ranges in plants

	Normal range in plants (ppm)	Mean range in tested plants (ppm)	Critical range in plants (ppm)	Toxicity Status
Cd	0.1 - 2.4	0.38 - 94.3	10 - 30	Critical
Co	0.75 - 1.07	3.1 - 28.4	1 - 8	Critical
Cu	7.53 - 8.44	11.4 - 52.8	25 - 90	Critical
Ni	0.89 - 2.04	8.52 - 52.1	10 - 50	Critical
Pb	0.2 - 2.0	5.32 - 96.12	30 - 300	Critical
Zn	1 - 400	69.4 - 632	100 - 400	Critical

Table 8: Concentration factor (CF) calculated for the various aquatic macrophytes species and the studied heavy metals in El-Temsah Lake

	<i>Myriophyllum spicatum</i>	<i>Ceratophyllum demersum</i>	<i>Eicchornia crassipes</i>	<i>Lemna gibba</i>	<i>Phragmites australis</i>	<i>Typha domingensis</i>
Cd	0.09	1.79	2.35	4.56	0.15	0.07
Co	0.71	17.35	23.50	1.57	1.75	1.71
Cu	1.88	74.97	96.30	2.37	3.24	3.85
Ni	1.06	30.63	48.09	2.27	5.24	3.16
Pb	8.94	163.34	208.71	9.57	2.32	1.31
Zn	2.66	903.30	1172.80	3.97	2.48	2.54
Mean	2.6	198.6	258.6	4.05	2.5	2.1
S D	3.3	350.1	453.8	2.9	1.7	1.4

range of the abovementioned heavy metals were evaluated according to [39] (Table, 7). It is worthy to mention that, the accumulation of all the investigated in the studied plants exceeded the normal rang and reached the critical range comparing with the standard normal ranges in plants, also, the mean values of concentrations of all the studied heavy metals within the six aquatic macrophytes exceeded the normal range (Table, 7).

Heavy Metals Translocation in Plants: The study of the accumulation characteristics of heavy metals in the different organs of the investigated aquatic macrophytes

and its transportation characteristics were evaluated through the calculation of three important relationships; concentration factor (C.F.), transfer factor (T.F.) and enrichment coefficient (E.C.) of roots, stems and leaves. The C.F. value for each individual heavy metal in all the studied aquatic macrophytes are shown in Table 8. The mean C.F. value of metals in the investigated plants increased according to the following plant sequence: *Typha domingensis* < *Phragmites australis* < *Myriophyllum spicatum* < *Lemna gibba* < *Ceratophyllum demersum* < *Eicchornia crassipes*. The pattern of C.F. value among the studied species

showed wide range of variation. The lowest C.F. value for Cd was recorded in *Myriophyllum spicatum* 0.09, while the highest one was 4.56 in *Lemna gibba*. On the other hand, *Eicchornia crassipes* recorded the highest C.F. value for Co, Cu, Ni, Pb and Zn as 23.5, 96.3, 48.09, 208.71 and 1172.8 respectively. In the same way, the lowest value of C.F. for Cd, Co, Cu, Ni were recorded in *Myriophyllum spicatum* 0.09, 0.71, 1.88 and 1.06 respectively. While the lowest C.F. value for Pb and Zn were scored by *Typha domingensis* (1.31) and *Phragmites australis* (2.48) respectively (Table 8).

The values of the transfer factor (T.F.) of the examined heavy metals in the investigated plants are shown in Table 9. The emergent aquatic macrophytes species *Typha domingensis* recorded the highest value of T.F. for Cd, Cu, Ni and Pb as 0.78, 0.99, 0.98 and 0.86 respectively. While, the highest values of C.F. were 0.24 and 1.09 which was scored by *Myriophyllum spicatum* and *Eicchornia crassipes* respectively. Alternatively, the lower values for T.F. for the metals Co, Cu and Zn were 0.17, 0.3 and 0.18 and recorded by *Ceratophyllum demersum*, additionally, *Lemna gibba* recorded the lowest values for T.F. in both Ni and Pb as 0.16 and 0.26 respectively and *Myriophyllum spicatum* and *Ceratophyllum demersum* recorded the lowest values for Cd and Zn as 0.24 and 0.18 in that order.

The enrichment coefficient was calculated for the roots (E.C.R) of the six investigated aquatic macrophytes (Table, 10). Regarding the mean value of the E.C.R it is ranged between 0.5 and 1.7 and decreased according to the following order: *Ceratophyllum demersum* > *Myriophyllum spicatum* > *Lemna gibba* > *Phragmites australis* > *Eicchornia crassipes* > *Typha domingensis*. It is worthy to mention that, the lowest values for the E.C.R for the metals Co, Cu and Ni were 0.13, 0.31 and 0.25 respectively and recorded for *Lemna gibba*. Additionally, *Typha domingensis* scored the lowest E.C.R values for Cd and Pb as 0.006 and 0.76. On the other hand, *Phragmites australis*, recorded the highest E.C.R values for Cd, Co and Ni as 0.019, 0.53 and 0.92 respectively. While the highest E.C.R values were for Pb and Zn and recorded for *Ceratophyllum demersum* as 7.89 and 0.52 respectively.

The values of the Enrichment coefficient for the stems (E.C.S) of the six investigated aquatic macrophytes are shown in (Table 8). The mean value of E.C.S ranged between 0.4 and 1.4 and according to the E.C.S the studied plants arranged according to the following descending order: *Ceratophyllum demersum* > *Myriophyllum spicatum* > *Lemna gibba* > *Phragmites australis* + *Eicchornia crassipes* > *Typha domingensis*. The lowest values of E.C.S for the heavy metals Co, Ni

Table 9: Transfer Factor (TF) calculated for the various aquatic macrophytes species and the studied heavy metals in El-Temsah Lake

	<i>Myriophyllum spicatum</i>	<i>Ceratophyllum demersum</i>	<i>Eicchornia crassipes</i>	<i>Lemna gibba</i>	<i>Phragmites australis</i>	<i>Typha domingensis</i>
Cd	0.244186	0.673913	0.65	0.258065	0.46875	0.785714
Co	0.394541	0.173554	1.095652	0.282609	0.711957	0.836364
Cu	0.500773	0.30839	0.644444	0.488095	0.909278	0.998099
Ni	0.172583	0.352204	0.829569	0.167715	0.963532	0.985163
Pb	0.265961	0.355701	0.672619	0.259117	0.703297	0.86631
Zn	0.277071	0.186902	0.814392	0.367274	4.837176	0.599283
Mean	0.3	0.3	0.8	0.3	1.4	0.9
S D	0.11	0.18	0.17	0.11	1.6	0.15

Table 10: Enrichment Coefficient (ECR) calculated for the roots of the aquatic macrophytes species and the studied heavy metals in El-Temsah Lake

	<i>Myriophyllum spicatum</i>	<i>Ceratophyllum demersum</i>	<i>Eicchornia crassipes</i>	<i>Lemna gibba</i>	<i>Phragmites australis</i>	<i>Typha domingensis</i>
Cd	0.010409	0.01114	0.00968	0.0075	0.01937	0.00678
Co	0.235123	0.35298	0.33547	0.13419	0.53676	0.48133
Cu	0.612922	0.83554	0.4263	0.3183	0.92099	0.99659
Ni	0.324013	0.40949	0.86179	0.25323	0.92196	0.59635
Pb	6.519704	7.89163	1.37931	4.2775	1.49425	0.76765
Zn	0.346939	0.52657	0.50354	0.21025	0.05781	0.30204
Mean	1.3	1.7	0.6	0.9	0.7	0.5
S D	2.5	3.1	0.5	1.7	0.6	0.4

Table 11: Enrichment Coefficient (ECS) calculated for the stems of the aquatic macrophytes species and the studied heavy metals in El-Temsah Lake

	<i>Myriophyllum spicatum</i>	<i>Ceratophyllum demersum</i>	<i>Eichhornia crassipes</i>	<i>Lemna gibba</i>	<i>Phragmites australis</i>	<i>Typha domingensis</i>
Cd	0.008715	0.009804	0.00581	0.006778	0.010409	0.004599
Co	0.178238	0.271295	0.245041	0.090432	0.33839	0.341307
Cu	0.500568	0.731338	0.318302	0.215991	0.689655	0.91133
Ni	0.162095	0.297293	0.640595	0.15077	0.872412	0.436206
Pb	5.156814	6.436782	0.752053	3.152709	0.935961	0.527094
Zn	0.309371	0.351937	0.483299	0.155269	0.364931	0.235319
Mean	1.1	1.4	0.5	0.6	0.5	0.4
S D	2.0	2.5	0.3	1.3	0.4	0.3

Table 12: Enrichment Coefficient (ECL) calculated for the leaves of the aquatic macrophytes species and the studied heavy metals in El-Temsah Lake

	<i>Myriophyllum spicatum</i>	<i>Ceratophyllum demersum</i>	<i>Eichhornia crassipes</i>	<i>Lemna gibba</i>	<i>Phragmites australis</i>	<i>Typha domingensis</i>
Cd	0.002542	0.00750424	0.00629388	0.00193658	0.00907771	0.00532559
Co	0.092765	0.06126021	0.36756126	0.03792299	0.38214702	0.40256709
Cu	0.306934	0.25767336	0.27472527	0.15536188	0.83743842	0.99469496
Ni	0.055919	0.14422226	0.71491771	0.04247036	0.88833835	0.58750664
Pb	1.73399	2.80706076	0.92775041	1.10837438	1.05090312	0.66502463
Zn	0.096127	0.09841733	0.41007913	0.07721783	0.27963349	0.18100791
Mean	0.4	0.6	0.5	0.3	0.6	0.5
S D	0.7	1.1	0.3	0.4	0.4	0.4

Table 13: Trophic classification system of water bodies (source OECD, 1982)

	Total Phosphorus ($\mu\text{g/l}$)	Chlorophyll <i>a</i> ($\mu\text{g/l}$)	Depth Secchi disc (m)
Ultra-Oligotrophic	<4	<1	>12
Oligotrophic	<10	<2.5	>6
Mesotrophic	10-35	2.5-8	6-3
Eutrophic	35-100	8-25	3-1.5
Hypertrophic	>100	>25	<1.5

and Zn were 0.09, 0.15 and 0.16 respectively and recorded for the free floating aquatic macrophytes species *Lemna gibba*. In contrast, the emergent aquatic macrophytes species *Phragmites australis* recorded the highest values of E.C.S for the metals Cd, Ni and Zn as 0.01, 0.87 and 0.36 respectively, while the highest E.C.S value for the other metals Co and Cu were 0.34 and 0.91 respectively in case of *Typha domingensis* (Table 11).

The calculated values for the enrichment coefficient of the leaves (E. C. L) of the studied plant species are presented in table 12. The leaves of *Lemna gibba* recorded the lowest values of E.C.L for Cd, Cu and Ni which scored 0.0019, 0.155 and 0.042 respectively. Additionally, the lowest E.C.L values for the metals Zn, Co and Pb were 0.096, 0.36 and 0.66 in the leaves of *Myriophyllum spicatum*, *Eichhornia crassipes* and *Typha domingensis*. The general pattern for E.C.L among the six studied aquatic macrophytes follows the subsequent descending order: (*Ceratophyllum demersum* and *Phragmites australis*) > (*Eichhornia crassipes* and *Typha domingensis*) > *Myriophyllum spicatum* > *Lemna gibba*.

DISCUSSION

The findings of the present study showed that the concentrations of the six investigated heavy metals in water, sediments and the studied aquatic plants of El-Temsah Lake exceeded the normal levels and reached toxic and even critical levels.

El-Temsah Lake is a complicated aquatic system due to its unique geographical location in the midway of the Suez Canal and the multiple water sources that enrich the lake. The nutrients concentrations in the lake water showed relatively high concentrations especially for all forms of nitrogen (nitrite, nitrate and ammonium). The source of high concentration due the drainage of the domestic sewage in the western lagoon of the lake and the agricultural drainage in the lake which is full of many nitrogenous fertilizers such as urea and nitrate salts. These results agreed with that recorded by [24, 28 & 42].

Similarly, the total phosphorous in the lake represented very high concentration compared with that previously reported by [23, 42,43]. This situation could be

attributed to the phosphate carrying fertilizers e.g. superphosphate and the eutrophication caused by wastewater input in the western side of the lake.

According to OECD [44] trophic state classification system of water bodies (Table, 13), the trophic status of El-Temsah Lake categorized as eutrophic, this is due to the continuous nutrients and organic matter loading through domestic sewage drains and agricultural drains this classification concurred with [23].

Aquatic macrophytes are generally influenced more by metals in sediments than by those in water, consequently, bioaccumulation is greater when sediments are heavy metal contaminated than water. In particular, once released into the aquatic habitat, a part of heavy metals is transferred to sediments by the process of adsorption onto suspended matter and sedimentation [45].

In this study the heavy metal concentration in the sediments of El-Temsah Lake recorded double or triple the concentration in Lake's water. This situation of the element accumulation in sediment is the result of long term exposure, whereas element concentrations in water are mainly the result of recent contamination [46]. Result of this study showed that the concentrations of metals were far higher in the sediment than in the lake water. The continuous discharge of clay rich freshwater from River Nile through Ismailia Sweet water canal increased the clay content of the bottom sediments of El-Temsah Lake, this clay with its colloidal nature attracted many heavy metal ions and caused the high concentrations of all heavy metals in the sediments than water. These results coincide with previous findings of some researchers [47- 51].

The heavy metal concentration in roots showed higher accumulation values than shoots this implies relevant availability in the sediments. Roots of *Phragmites australis* and *Typha domingensis* accumulated a great quantity of heavy metals because of their cortex parenchyma with large intercellular spaces [52]. Previous studies on the accumulation of various heavy metals by aquatic macrophytes have also shown that the accumulation of most heavy metals was higher in roots than stems and leaves [53-55].

Despite their reduced poorly developed root system submerged and free floating aquatic macrophytes absorbed heavy metal in a noticeable concentration. The high concentrations of Cd, Cu, Ni and Zn in the tissues of *Lemna gibba* recommended the use of this promising free floating plant in the removal of heavy metals from various polluted waters.

The results of the present study agreed with that previously reported by [56-58]. Similarly, *Ceratophyllum demersum* and *Myriophyllum spicatum* accumulated studied heavy metals efficiently, the results of the current study was in the same opinion with that recorded by [10, 59, 60].

The behavior of an organism in its habitat reflect the environmental pollution when it has the potentiality to accumulate elements proportionally to their concentration in the environment [61]. The selected aquatic macrophytes in the current study showed different heavy metal concentration ranges, depending on the plant organ, their roots more efficiently absorbed heavy metals from the surrounding environment and accumulated high concentrations within root tissues these results agreed with that previously documented by [46]. Similarly, [62] reported that heavy metal uptake and accumulation in the different plant organs depend on the concentration of the available metals in the surrounding environment, solubility sequence and plant species its self.

The high values of concentration factor (C.F) in *Eichhornia crassipes* and *Ceratophyllum demersum* previously explained by their powerful ability to uptake and accumulate heavy metals from the adjacent aquatic environment. The values of C.F obtained in this study agree with that previously reported by [61, 63, 64].

Regarding the transfer factor (T.F) the obtained results in the present study for the six investigated aquatic macrophytes exhibit different heavy metal concentrations. T.F is used to estimate plant's potential for phytoremediation purpose. The T.F factor within the investigated macrophytes indicates the efficient way of transportation of metal from root and its accumulation in shoots (leaves and stems) [65]. The variation of T.F values among the investigated aquatic macrophytes indicate that each metal has specific phytotoxic effect on these plants. According to [66, 67] the T.F values are three major classes; T.F value higher than 1.0 were determined in metal accumulator species e.g. *Eichhornia crassipes*, whereas, T.F was typically lower than 1.0 in metal excluder species e.g. *Phragmites australis*, *Typha domingensis*, *Lemna gibba*, *Myriophyllum spicatum*. The T.F higher than 1.0 indicate an efficient ability to transport metal from root to leaf, most likely due to efficient metal transporter system [68] and probably by sequestration of metals in leaf vacuoles and apoplast [69].

Enrichment coefficients (E.C) for the various plant organs (roots, stems and leaves) are very important indicator for the phytoremediation ability of a given

species [68]. This E.C reflects the values of heavy metal concentration in the plant organ in relation to the surrounding environment.

The highest values for enrichment coefficient in roots (E.C.R) were calculated for lead metal in the roots for all the investigated aquatic macrophytes. Previous studies on the accumulation of metal ions by aquatic plants have shown that the deposition of most metals was higher in roots than shoots [14, 54, 70]. These findings are in line with the results of the present study. This means that the roots of the investigated species have an important capacity in the accumulation process of the heavy metals.

The highest E.C.R value was calculated for the submerged aquatic macrophytes *Ceratophyllum demersum* and *Myriophyllum spicatum*, this is due to their ability to extract metals from the sediments via their root systems and directly from the surrounding water via their shoot [71].

Regarding the enrichment coefficient values in stems (E.C.S) it showed high values which is mostly related to the ability of aquatic plants to influence the heavy metal uptake and accumulation by modifying the substratum through oxygenation, buffering pH and adding organic matter through decayed parts [72].

The values for enrichment coefficient in leaves (E.C.L) were calculated for the investigated six aquatic macrophytes and showed higher than 1.0 values in most of them. Several previous studies concluded that this situation indicated special ability of the plant to absorb and transport metals from sediment and then stored them in their shoots especially leaves due to their high replacement rate [13].

CONCLUSION

The present study revealed that the concentration of the investigated metals (Cd, Co, Cu, Ni, Pb, Zn) in the surface water and sediments of El-Temsah Lake exceeded the critical ranges stated by the Egyptian Environmental Affairs Agency and reached toxic level. Unfortunately, people inhabiting in that area catch fish and crustacean as food source from the sampling stations. This situation threaten the public health and thus care should be taken when dealing with fish obtained from this polluted lake. Similarly, the inspected native aquatic plant species showed higher levels of heavy metals accumulation which has the potential to be used in the phytoremediation purposes to remove heavy metals from the lake. on the other hand, these plants shouldn't be used as a fodder for livestock and wild animal to avoid the translocation of

these metals in the food chain. Intensive prospective studies should be performed on the plants and fish in the region to monitor the heavy metal concentration in El-Temsah Lake ecosystem.

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