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Heavy-metals contamination in three drains along the Nile delta of Egypt: Assessment and phytoremediation aspects

Aya M. El-Shiekh, Ghada A. El-Sherbeny, Ibrahim A. Mashaly, Mohamed Abdelaal

Botany Department, Faculty of Science, Mansoura University, Mansoura 35516, Egypt

**** Correspondence to:** Email: Mohamed_eco@mans.edu.eg*

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Abstract: Serious global problems could arise from excessive levels of heavy metals released into the environment as a result of sewage, chemical fertilizers, human activities, and non-biodegradable industrial wastes. With an emphasis on evaluating the sources of pollution and the possibility of phytoremediation using three perennial aquatic macrophytes (*Eichhornia crassipes* L., *Ludwigia stolonifera* L., and *Pistia stratiotes* L.), this study examined the levels of heavy metal contamination in three drainage systems along Egypt's Nile Delta: Faraskour, El-Serw, and Hadous. Heavy metal concentrations such as iron (Fe), copper (Cu), lead (Pb), cadmium (Cd), cobalt (Co), manganese (Mn), nickel (Ni), and zinc (Zn) were measured in sediment, water, and plant samples. Additionally, two phytoremediation factors—bioaccumulation factor (BF) and translocation factor (TF)—were estimated for every plant. The findings showed that the three drains' sediment heavy-metal concentrations happened in the following order: El-serw > Faraskour > Hadous. The sediment heavy-metal concentrations in the three drains were roughly arranged as follows: Fe (0.86-0.89 mg kg^{-1}) > Mn (0.7-0.65 mg kg^{-1}) > Cu (0.4519-0.4522 mg kg^{-1}) > Pb (0.21-0.22 mg kg^{-1}) > Cd (28.39-59.21 mg kg^{-1}) > Ni (25.6-32.67 mg kg-1) > Co (2.53-3.16 mg kg^{-1}) > Zn (2.28-2.35 mg kg^{-1}). For heavy metal phytoremediation, *E. crassipes* showed the most promise, particularly for Fe, Mn, Pb, Zn, Cu, Ni, and Co. For Cd, *L. stolonifera* was the most successful. The results highlight how phytoremediation may be used as a long-term way to reduce heavy metal pollution in drainage systems. It is advised that immediate action be taken to save Egypt's Nile Delta ecology, which includes building water treatment facilities and improving wastewater management techniques.

Keywords: Phytoextraction, emergent hydrophytes, pollution, bioaccumulation factor, translocation factor

1.Introduction

Water scarcity and quality degradation are among the most pressing global challenges of the 21st century. These issues are expected to intensify in the coming years due to the combined effects of human activities [1]. In many African countries, including Egypt, rapid population growth, industrial and agricultural expansion, has led to a significant increase in pollutant discharge into water bodies, resulting in severe impacts on aquatic ecosystems. For Egypt, the dual pressures of a growing population and reduced water availability—exacerbated by projects like the Ethiopian Dam—pose a critical threat to its water resources [2]. Furthermore, pollutants such as chemical fertilizers, pesticides, organic waste, and untreated industrial and domestic effluents have increasingly been released into irrigation and drainage canals connected to the Nile River, amplifying the environmental stress on the region [3]. Addressing these challenges requires sustainable water resource management and innovative approaches to wastewater reuse to mitigate the anticipated impacts of water scarcity [2]. Recently, the issue of heavy metal contamination in aquatic environments has gained significant attention. Human activities, including industrial discharges, chemical fertilizer application, and the release of non-biodegradable waste, have contributed to the excessive deposition of heavy metals in water systems. This contamination poses severe risks due to the toxicity, persistence, and bioaccumulative nature of heavy metals in ecosystems [4-5]. Heavy metals are particularly dangerous because of their toxicity, persistence, and environmental bioaccumulation. [6]. These metals cannot be broken down if they are discharged into sediment, soil, or water. Instead, they will pass via aquatic animals and plants and end up in the food chain [7-9]

Among the most common heavy metals found in natural environments are cobalt (Co), cadmium (Cd), nickel (Ni), and lead (Pb), which are toxic even at low concentrations. While essential trace elements like iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) are necessary for biological functions at minimal levels, their solubility and mobility can render them harmful at higher concentrations [9].

To mitigate heavy metal contamination, several phytoremediation techniques have been explored, including phytostabilization, phytoextraction, and rhizofiltration [20]. Phytoextraction is the process by which belowground roots remove metal or pollutants from the soil or water, whereas phytostabilization is the capacity of a plant species to immobilize heavy metal and deposit it in its below-ground tissues [21].

Because aquatic macrophytes and wetland plants can transfer high concentrations of metals from surrounding environments (sediment or water) to their aboveground tissues (leaf, stem, etc.) without impeding plant growth, they are ideal candidates for use in phytoremediation techniques [22, 23] Three major drains (Faraskour & El-Serw and Hadous) that run north of Egypt's Nile Delta have been subjected to exponentially increasing levels of severe pollution in recent years due to human activity. Heavy metals and other solid, non-biodegradable wastes were among the things that contaminated these drains from industrial, agricultural, and urban wastes. Heavy metals and other solid, non-biodegradable wastes were among the things that contaminated these drains from municipal, industrial, and agricultural wastes. To the best of our knowledge, the three drains' heavy metal content and pollution status have not been the subject of any prior research

To evaluate the phytoremediation potential of three perennial aquatic macrophytes—. *E. crassipes, L. stolonifera* and *P. stratiotes.* —we evaluated their phytoremediation potential in this study. These species are widely distributed, exhibit rapid growth, and have high biomass, making them suitable for heavy metal accumulation [8, 14, 15, 22, 24, 25]. Therefore, the goals of the current investigation were to: 1) determine the heavy-metals concentrations in the sediment and 2) assess the chosen plants phytoremediation capacity.

2. Materials and Methods

2.1. Study area

The present study investigated three major drains in the Nile Delta region of Egypt: Faraskour, El-Serw, and Hadous (Figure 1). Faraskour and El-Serw drains primarily serve as conduits for agricultural wastewater from the Nile Delta, eventually discharging into the Mediterranean Sea, the Hadous drain directly discharges into the Nile River.

The Faraskour Drain is located in the Damietta Governorate of Egypt. It is a significant drainage system that helps manage agricultural runoff and drainage in the region. The drain is near the city of Faraskour, part of the Damietta Governorate, in the northeastern country, close to the Mediterranean coast. The area is primarily agricultural, with the drain playing a crucial role in irrigation and drainage management for the surrounding farmland.

The Faraskour Drain is approximately 40 kilometers (about 25 miles) long. As for its width, it can vary along different segments, but it typically ranges from 5 to 10 meters wide (16 to 33 feet). El-Serw Drain, located in El-Dakahlia Governorate of Egypt, serves as an important drainage system for the surrounding agricultural land. It helps manage excess water and prevent flooding, thereby supporting agricultural activities in the region.

Regarding its dimensions, El-Sarw Drain is approximately 100 kilometers (about 62 miles) long. The width of the drain varies but typically ranges between 5 to 10 meters (approximately

16 to 33 feet) , depending on the specific section and its intended function.

Hadous Drain is another important drainage canal in the Nile Delta region of Egypt. It plays a critical role in the agricultural irrigation and drainage system by helping to manage excess water and prevent soil salinity, which is vital for agricultural productivity in the area - Location: Primarily located in El-sharkia Governorate of Egypt - Length**:** The Hadous Drain is approximately 80 kilometers (about 50 miles) long. - Width: Like other drainage canals, the width can vary, often around 5 to 10 meters (approximately 16 to 33 feet).

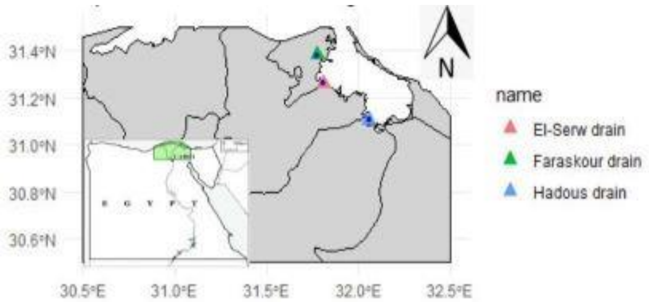


Figure (1). The study area showing the three drains.

2.2. Sampling design and processing

Three floating perennial plant species were selected for the study. Sediment, soil, and plant samples (n=3) were collected during the winter of 2021 from three key locations in each drain: upstream, midstream, and downstream (Figure 1). A total of 27 composite samples (9 sites × 3 samples per site) were analyzed. Sites were chosen based on pollution levels and presence of the selected plant species. Plant identification followed the methodology described in reference [26].

2.3. Water analysis

Water samples were collected seasonally over a year to assess temporal variations. Samples were taken at three strategic points in each drain, including upstream, midstream, and downstream areas. They were collected in acid-washed polyethylene bottles, preserved at 4°C, and analyzed. The pH, (EC), and (TDS) of water samples were measured in field.

2.4. Sediment soil analysis

Sediment samples were extracted from a depth of 0 to 30 cm. After air-drying, the samples were powdered and sieved with a 2 mm mesh. digested samples were then diluted with deionized water to a constant volume [27].

2.5. Plant analysis

Healthy plant samples were collected in plastic bags and thoroughly cleaned with distilled water. Samples were separated into above-ground and below-ground tissues, the filtrate was diluted to a specific volume with deionized water [8,28]. Heavy metal concentrations were measured using the same spectrophotometer as above.

2.6. Phytoremediation potentials

Two factors were used to determine how well the above-ground and below-ground organs of the chosen macrophytes accumulated heavy metals from sediment: the translocation factor (TF) and the bioaccumulation factor (BF). While TF represents the transfer of heavy metal from below-ground organs to above-ground organs, BF measures the plant organs' capacity to absorb the metal from the sediment. Here, the following equations were used to determine BF and TF:

$BF = C_{\text{below-ground}} / C_{\text{sediment}}$,

$TF = C_{\text{above-ground}} / C_{\text{below- ground}}$,

The concentrations (mg kg-1) in tissues of chosen plant species are denoted by the symbols $C_{\text{above-ground}}$ and $C_{\text{below-ground}}$ respectively . while C sediment refers to the heavy-metal concentration in the corresponding sediment soil [24, 29–30].

3.Results.

3.1. Water heavy metals

The analysis of water revealed significant differences in heavy metal concentrations among the three drains (Fig.2). Hadous Drain exhibited the highest mean concentrations for all measured metals (Fe: 64.39 mg kg^{-1}, Mn: 1.7 mg kg^{-1}, Pb: 1.4 mg kg^{-1}, Zn: 28.95 mg kg^{-1}, Cu: 17.72 mg kg^{-1}, Ni: 1.4 mg kg^{-1}, Co: 13.37 mg kg^{-1}, Cd: 1.59 mg kg^{-1}, and Hg: 0.085 mg kg^{-1}). Conversely, El-Serw Drain. Meanwhile, the lowest levels of Mn, Pb, Zn, and Hg were recorded in Faraskour Drain (1.52, 0.44, 17.5, and 0.01 mg kg^{-1}, respectively)

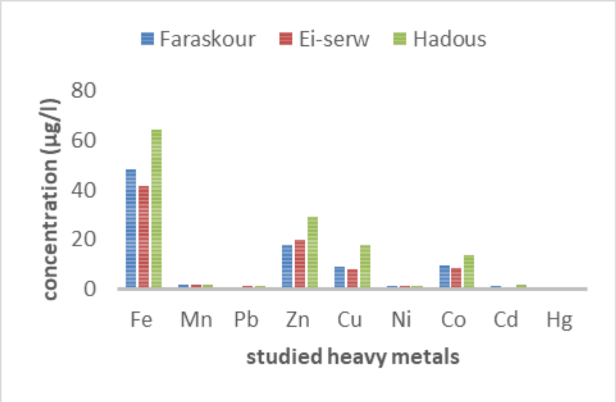
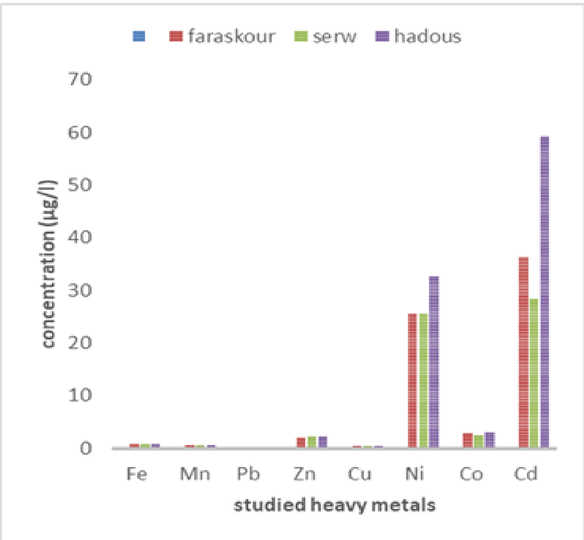


Figure (2). Concentration of the studied heavy metals in the three drains.

3.2. Sediment heavy metals in the examined drains

The concentrations of heavy metals in the sediments of the three examined drains revealed significant differences ($p \leq 0.05$) (Figure 3). The order of sediment heavy-metal concentrations was as follows: Hadous > Faraskour > El-Serw. For all drains, the metal concentrations followed the same descending order: Cd > Ni > Co > Zn > Fe > Mn > Cu > Pb. Among the drains, Hadous showed the highest average concentrations of Fe, Mn, Pb, Zn, Cu, Ni, Co, and Cd (0.89, 0.64, 0.22, 2.35, 0.45, 32.67, 3.16, and 59.21 mg/kg, respectively). Drain.



(Figure.3) Concentration of heavy metals in the sediment of investigated three drains

3.3. Heavy metals in plants

The concentrations of heavy metals in the above-ground and below-ground tissues of the three studied plan species are summarized in Table 2. Statistical analysis (ANOVA) revealed significant differences in heavy-metal concentrations among species and tissue types ($p \leq 0.05$) (Figure 4). Except for Cd and Pb in *L. stolonifera*, all species exhibited higher metal accumulation in below-ground tissues compared to above-ground tissues. Among the studied species, *E. crassipes* showed the highest accumulation of Fe, Mn, Zn, Pb, Cu, Co, and Ni in its tissues, whereas *L. stolonifera* had the highest Cd concentrations.

3.4. Phytoremediation potential of plant species

The bioaccumulation factor (BAF) and translocation factor (TF) are critical indicators for evaluating a plant's ability to accumulate and translocate heavy metals from its environment (soil and water) into its tissues. The results of BAF and TF for the three plant species are presented in Table 2 and Figure 4. *E. crassipes* exhibited the highest BAFshoot and BAFroot for Fe (869.96 and 1863.68, respectively), Conversely, the lowest BAFshoot (90.19), BAFroot (156.4), and TF (0.466) for Fe were recorded *in P. stratiotes, L. stolonifera, and E. crassipes*, respectively. For Mn, the highest BAFshoot (1581.5) and BAFroot (2423.93) were observed in *E. crassipes*. Overall, *E. crassipes* exhibited the maximum BAFshoot and BAFroot for most metals except Cd. In contrast, *L. stolonifera* showed the highest BAFshoot, BAFroot, and TF for Cd. The study revealed that *E. crassipes* recorded the highest BAFshoot (869.96, 1581.94, 1081.7, 146.49, 161.9, 3.2, and 7.37 for Fe, Mn, Pb, Zn, Cu, Ni, and Co, respectively) and BAFroot (1863.68, 2423.9, 1577.15, 240.45, 316.1, and 12.2 for the same metals). On the other hand, *Pistia stratiotes* exhibited the lowest BAFshoot, BAFroot, and TF for most metals, except for Cd, where *L. stolonifera* had the highest values (BAFshoot = 1.72, BAFroot = 1.27, and TF = 1.36). The bioaccumulation factors (BAFs) for the studied species were greater than one for all heavy metals except Cd in *E. crassipes* and *P. stratiotes* and Ni in the BAFshoot of P. stratiotes. However, the translocation factors (TFs) for all species, except for Cd in *L. stolonifera and P. stratiotes* and Pb in *L. stolonifera*, were less than one.

Based on BAF values, the plant species ranked as follows for Fe, Mn, Pb, Zn, Ni, and Co: *E. crassipes* > *L. stolonifera* > *P. stratiotes.* For Cd, the ranking was*: L. stolonifera* > *E. crassipes* > *P. stratiotes.*

When analyzing water samples, Hadous Drain was confirmed as the most polluted, with iron (Fe) being the most abundant element, ranging from 41.46 mg/kg to 64.39 mg/kg. This result is consistent with iron's essential biological role in aquatic ecosystems. Iron typically exists in two oxidation states: ferric (Fe^{3+}), which is insoluble, and ferrous (Fe^{2+}), which is soluble in aqueous environments [40,41]. Comparatively, the mean concentrations of Fe, Mn, Zn, Cd, and Pb in the study were lower than those reported in earlier research on the same drains connected to Lake Manzala (787 mg/kg for Fe, 575 The lowest lead (Pb) concentration (0.44 mg/kg) was recorded in Faraskour Drain, consistent with previous findings [43]. El-Badry [44] also noted the highest concentrations of cadmium, lead, nickel, and

zinc in the eastern section of Lake Manzala near Hadous Drain, while the lowest levels were observed in the western section near El-Serw Drain. Copper (Cu) and cobalt (Co) were higher in the western area near El-Serw Agricultural Drain, consistent with the present study's results. The ability of aquatic macrophytes to hyperaccumulate and translocate heavy metals varies depending on factors such as location, plant species, tissue type, pH, and redox potential [9,49,50]. In this study, *E. crassipes* demonstrated the highest accumulation of Fe, Mn, Zn, Pb, Cu, Co, and Ni, while *L. stolonifera* showed the highest accumulation of Cd. Despite variations, all tested plant species absorbed considerable concentrations of the studied heavy metals. These differences may be attributed to factors such as pollution levels, sampling time, extraction methods, and the physicochemical properties of watercourses [8,35,36]. Effective phytoremediation plants, like hyperaccumulators, exhibit superior metal uptake and sequestration capabilities [50]. In this study, *E. crassipes* showed the highest Fe and Mn concentrations in both above-ground and below-ground tissues, consistent with previous findings [37]. Additionally, *L. stolonifera* accumulated trace metals more efficiently in its roots than in shoots, a common compartmentalization strategy among aquatic plants to protect against metal toxicity [49]. Saleh et al. (2019) [48] reported that living parts of *L. stolonifera* effectively remediate Cd, Pb, and Cr from polluted water.

The bioaccumulation factor (BF) offers insights into a plant's efficiency in metal uptake. Plants with BF values >1.0 are considered accumulators, while those with values <1.0 are excluders [46,47]. In this study, all plant species displayed BF values >1.0 for most heavy metals, indicating their phytoremediation potential. Among the metals, manganese (Mn) showed the highest BF, followed by Fe, Pb, Cu, Zn, Co, Ni, and Cd.

(Table1.) Heavy-metals concentration (mean ± standard error) in the above-ground (AG) and below-ground (BG) tissues of the study plant species collected from the three drains in the Nile Delta of Egypt. Different letters indicate significant differences among species as well as metals ($p \leq 0.05$).

Species	Tissue	Heavy-metal (mg kg^{-1})							
		Fe	**Mn**	**Pb**	**Zn**	**Cu**	**Ni**	**Co**	**Cd**
Eichhornia crassipes	AG	790.58± 2.72^{ab}	1105.39± 82.26^{a}	229.99± 16.47^{a}	323.51± 14.60^{a}	74.85± 6.85^{a}	89.2± 0.60^{a}	21.20± 1.86^{a}	28.75± 3.36^{ab}
	BG	1693.63 ± 23.34^{a}	1694.22± 47.47^{a}	335.33± 27.86^{a}	531.02± 39.73^{a}	146.11± 6.72^{a}	100.22± 6.26^{ab}	35.11± 3.19^{a}	39.78± 2.21^{a}
Pistia stratiotes	AG	81.96± 8.31^{ab}	23.82± 3.30^{ab}	25.00± 2.39^{ab}	23.12± 6.71^{ab}	28.85± 4.96^{ab}	20.38± 4.08^{ab}	7.57± 0.76^{ab}	6.77± 0.77^{ab}
	BG	172.51± 14.26^{ab}	56.98± 6.83^{ab}	42.09± 7.45^{ab}	128.79± 7.04^{ab}	74.71± 3.06^{ab}	68.9± 5.85^{ab}	16.81± 1.31^{ab}	6.77± 1.17
Ludwigia stolonifera	AG	123.81± 3.48^{b}	97.38± 4.46^{ab}	198.7± 6.35^{ab}	63.10± 3.45^{b}	12.46± 0.82^{ab}	69.63± 2.88^{ab}	10.26± 0.62^{ab}	71.24± 2.04^{ab}
	BG	142.13± 9.04^{b}	147.68± 21.76^{ab}	72.37± 4.09^{ab}	147.06± 7.35^{b}	37.54± 3.80^{b}	95.36± 4.99^{b}	16.47± 3.44^{b}	52.42± 7.38^{ab}

Table (2). Bioaccumulation factor (BAF) from the sediment to roots and translocation factor (TF) from roots to shoots of heavy metals in the three plant species grown in the studied drains
Discussion

Species	Factor	Heavy-metal							
		Fe	**Mn**	**Pb**	**Zn**	**Cu**	**Ni**	**Co**	**Cd**
Eicchornia crassipes	BAF shoot	869.96	1581.49	1081.72	146.49	161.92	3.19	7.37	0.69
	BAF root	1863.68	2423.93	1577.15	240.45	316.08	3.58	12.20	0.96
	TF	0.4668	0.65	0.68	0.60	0.51	0.89	0.60	0.72
Pistia stratiotes	BAF shoot	90.18	34.08	117.61	10.47	62.40	0.73	2.63	0.16
	BAF root	189.83	81.53	197.95	58.32	161.63	2.46	5.84	0.16
	TF	0.47	0.41	0.59412	0.179	0.38	0.29	0.45	1.00
Ludwigia stolonifera	BAF shoot	136.24	139.32	117.611	28.57	26.95	2.49	3.56	1.72
	BAF root	156.40	211.29	340.36	66.59	81.22	3.41	5.72	1.26
	TF	0.87	0.65	2.74	0.42	0.33	0.73	0.62	1.35

Conclusion

The study investigated heavy metal contamination in three drainage systems in the Nile Delta (Faraskour, El-Serw, and Hadous) and assessed the phytoremediation potential of selected aquatic plants. accumulation levels but showed notable translocation for certain metals.

References

1. Schwarzenbach, R. P.; Egli, T.; Hofstetter, T. B.; Von Gunten, U.; Wehrli, B. Global (2010) Water Pollution and Human Health. Annu. Rev. Environ. Resour., , **35**, 109–136.
2. Abdelhafez, A. A.; Metwalley, S. M.; Abbas, H. H. Irrigation: (2020) Water Resources, Types and Common Problems in Egypt. In Technological and Modern Irrigation Environment in Egypt; Springer,; pp 15–34.
3. Authman, M. M. N.; Abbas, W. T.; Gaafar, A. Y. (2012) Metals Concentrations in Nile Tilapia

   Oreochromis niloticus from Illegal Fish Farm in Al-Minufiya Province, Egypt, and Their Effects on Some Tissues Structures. Ecotoxicol. Environ. Saf., , **84**, 163–172.
4. Garbisu, C.; Alkorta, I. (2003) Basic Concepts on Heavy Metal Soil Bioremediation. ejmp ep *(European J. Miner. Process. Environ. Prot.*, , **3 (1),** 58–66.
5. Eid, E. M.; Galal, T. M.; Shaltout, K. H.; El-Sheikh, M. A.; Asaeda, T.; Alatar, A. A.; Alfarhan, A. H.; Alharthi, A.; Alshehri, A. M. A.; Picó, Y. (2020) Biomonitoring Potential of the Native Aquatic Plant *Typha domingensis* by Predicting Trace Metals Accumulation in the Egyptian Lake Burullus. Sci. Total Environ., , **714**, 136603.
6. Gall, J. E.; Boyd, R. S.; Rajakaruna, N. (2015) Transfer of Heavy Metals through Terrestrial Food Webs: A Review. Environ. Monit. Assess., , **187 (4)**, 1–21.
7. Ma, Y.; Prasad, M. N. V; Rajkumar, M.; Freitas, H. (2011) Plant Growth Promoting Rhizobacteria and Endophytes Accelerate Phytoremediation of Metalliferous Soils. Biotechnol. Adv., , **29 (2)**, 248–258.
8. Eid, E. M.; Galal, T. M.; Sewelam, N. A.; Talha, N. I.; Abdallah, S. M. (2020) Phytoremediation of Heavy Metals by Four Aquatic Macrophytes and Their Potential Use as Contamination Indicators: A Comparative Assessment. Environ. Sci. Pollut. Res., , **27 (11),** 12138–12151.
9. Tekin-Özan, S. (2008) Determination of Heavy Metal Levels in Water, Sediment and Tissues of Tench (*Tinca tinca* L., 1758) from Beyşehir Lake (Turkey). Environ. Monit. Assess., , **145 (1),** 295–302.
10. .Satpathy D., Reddy M.V., Dhal S.P. Risk (2014) assessment of heavy metals contamination in paddy soil, plants, and grains (Oryza sativa L.) at the East Coast of India. Biomed Res. Int. 2014;:545473. doi: 10.1155/2014/545473. [DOI] [PMC free article] [PubMed] [Google Scholar]
11. Esposito F., Nardone A., Fasano E., Scognamiglio G., Esposito D., Agrelli D., Ottaiano L., Fagnano M., Adamo P., Beccaloni E. (2018) A systematic risk

characterization related to the dietary exposure of the population to potentially toxic elements through the ingestion of fruit and vegetables from a potentially contaminated area. A case study: The issue of the" Land of Fires" area in Campania region, Italy. Environ. Pollut.;**243**:1781–1790. doi: 10.1016/j.envpol.2018.09.058. [DOI] [PubMed] [Google Scholar] 2020 Jul 18;**9(7)**:910. doi: 10.3390/plants9070910

12. Farahat, E. A.; Galal, T. M. (2018) Trace Metal Accumulation by Ranunculus sceleratus: Implications for Phytostabilization. Environ. Sci. Pollut. Res., , **25 (5)**, 4214–4222.
13. Hegazy, A. K.; Abdel-Ghani, N. T.; El-Chaghaby, G. A. (2011) Phytoremediation of Industrial Wastewater Potentiality by Typha Domingensis. Int. J. Environ. Sci. Technol., , **8 (3)**, 639–648.
14. Saha, P.; Shinde, O.; Sarkar, S. (2017) Phytoremediation of Industrial Mines Wastewater Using Water Hyacinth. *Int. J. Phytoremediation*, , **19 (1)**, 87–96.
15. Peng, K.; Luo, C.; Lou, L.; Li, X.; Shen, Z. (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 Wastewater Treatment. Sci. Total *Environ.*, , **392 (1),** 22–29. https://doi.org/10.1016/j.scitotenv.2007.11.032.
16. Fawzy, M. A.; Badr, N. E.; El-Khatib, A.; Abo-El-Kassem, A. (2012) Heavy Metal Biomonitoring and Phytoremediation Potentialities of Aquatic Macrophytes in River Nile. Environ. Monit. Assess., **184 (3)**, 1753–1771.
17. Kassaye, Y. A.; Skipperud, L.; Einset, J.; Salbu, B. (2016) Aquatic Macrophytes in Ethiopian Rift Valley Lakes; Their Trace Elements Concentration and Use as Pollution Indicators. Aquat. Bot., **134** 18–25. https://doi.org/10.1016/j.aquabot.2016.06.004.
18. Eid, E. M.; Shaltout, K. H.; Moghanm, F. S.; Youssef, M. S. G.; El-Mohsnawy, E.; Haroun, S. A (2019) Bioaccumulation and Translocation of Nine Heavy Metals by *Eichhornia crassipes* in Nile Delta, Egypt: Perspectives for Phytoremediation. *Int. J. Phytoremediation*, **21 (8)**, 821–830.
19. Galal, T. M.; Al-Sodany, Y. M.; Al-Yasi, H. M. (2020) Phytostabilization as a Phytoremediation Strategy for Mitigating Water Pollutants by the Floating Macrophyte *Ludwigia stolonifera* (Guill. & Perr.) PH Raven. *Int. J. Phytoremediation* , **22 (4),** 373–382.
20. Boulos, L. (2009) Flora of Egypt Checklist, Revised Annotated Edition; Al Hadara Publishing: Cairo,.
21. Otte, M. L.; Haarsma, M. S.; Broekman, R. A.; Rozema, J. (1993) Relation between Heavy Metal Concentrations in Salt Marsh Plants and Soil. Environ. Pollut , **82 (1)**, 13–22
22. Lu, R. K. (2000) Methods of Inorganic Pollutants Analysis. Soil agro-chemical Anal. methods, , 205–266.
23. Farahat, E.; Linderholm, H. W. (2015) The Effect of Long-Term Wastewater Irrigation on Accumulation and Transfer of Heavy Metals in Cupressus Sempervirens Leaves and Adjacent Soils. Sci. Total Environ., **512**, 1–7.
24. Gupta, S.; Nayek, S.; Saha, R. N.; Satpati, S. (2008) Assessment of Heavy Metal Accumulation in Macrophyte, Agricultural Soil, and Crop Plants Adjacent to Discharge Zone of Sponge Iron Factory. Environ. Geol., **55 (4),** 731–739.
25. El-Amier, Y. A.; Bonanomi, G.; Al-Rowaily, S. L.; Abd-ElGawad, A. M. (2020) Ecological Risk Assessment of Heavy Metals along Three Main Drains in Nile Delta and Potential Phytoremediation by Macrophyte Plants. Plants, **9 (7),** 910.
26. Aitta, A.; El-Ramady, H.; Alshaal, T.; El-Henawy, A.; Shams, M.; Talha, N.; Elbehiry, F.; Brevik, E. C. (2019) Seasonal and Spatial Distribution of Soil Trace Elements around Kitchener Drain in the Northern Nile Delta, Egypt. Agriculture, **9 (7)**, 152.
27. EEAA, E. E. A. A. (2008) Egyptian State of the Environment Report; Cairo
28. Bragato, C.; Brix, H.; Malagoli, M. (2006) Accumulation of Nutrients and Heavy

Metals in Phragmites australis (Cav.) Trin. Ex Steudel and Bolboschoenus maritimus *(L.*) Palla in a Constructed Wetland of the Venice Lagoon Watershed. Environ. Pollut., **144 (3)**, 967–975.

29. Du Laing, G.; Van de Moortel, A. M. K.; Moors, W.; De Grauwe, P.; Meers, E.; Tack, F. M. G.; Verloo, M. G. (2009) Factors Affecting Metal Concentrations in Reed Plants (Phragmites australis) of Intertidal Marshes in the Scheldt Estuary. Ecol. Eng., **35 (2)**, 310–318
30. Du Laing, G.; Tack, F. M. G.; Verloo, M. G. (2003) Performance of Selected Destruction Methods for the Determination of Heavy Metals in Reed Plants (Phragmites australis). Anal. Chim. Acta, , **497 (1–2)**, 191–198.
31. Agunbiade, F. O.; Olu-Owolabi, B. I.; Adebowale, K. O. (2009) Phytoremediation Potential of Eichhornia crassipes in Metal-Contaminated Coastal Water. Bioresour. Technol., **100 (19)**, 4521–4526.
32. Wang Haiyan and Arne O.Stuanes (2003) Heavy metal pollution in air-water-soil-plant systems,**147**: 79–107© 2003 Kluwer Academic Publishers. Printed in the Netherland.
33. Elsokkary LH, Muller G. (1990) Assessment and speciation of chromium, nickel, lead and chromium in the sediments of the river Nile. Egypt Sci Total Environ;97/**98**:455–63.
34. Cole, G. A. (1979). Text book of limnology. 2nd Edition, St. Louis, Toronto, London, 401 pp. C.V. Mosby Company.
35. El-Enany, H. R. (2004). Ecological and biological studies on Lake Manzalah with special reference to their water quality and sediment productivity. M. Sc.Thesis, Fac. Sci., Al-Azhar Univ., 386 pp.
36. Ali, M. (2008) Assessment of some water quality characteristics and determination of some heavy metals in Lake Manzala, Egypt. Egypt. *J. Aquat. Biol. Fish*., **12**, 133–154.
37. Hegazy, W. H., Hamed, M. A., Toufeek, M. E. S., & Mabrouk, B. K. A. (2016). Determination of some heavy metals in water of the southern region of Lake Manzala. Egypt. Egyptian *Journal of Aquatic Biology and Fisheries*, **20(4)**, 69–81.
38. El-Badry, A.E.A. (2016). Distribution of Heavy Metals in Contaminated Water and Bottom Deposits of Manzala Lake, Egypt. *J Environ Anal Toxicol*., **6**: 344.
39. Abu-Ziada ME (2007) Ecological studies on the aquatic macrophytes II*: Ludwigia stolinefera* (Guill. & Perr.) P.H. Raven. Pak *J Biol Sci* **10**: 2025–2038.
40. Bose S, Vedamati J, Rai V, Ramanathan AL. (2008). Metal uptake and transport by Typha angustata L. grown on metal contaminated waste amended soil: an implication of phytoremediation. Geoderma. **145(1–2)**:136–142.
41. Zu YQ, Li Y, Chen JJ, Chen HY, Qin L, Schvartz C. (2005). Hyperaccumulation of Pb, Zn and Cd in herbaceous grown on lead- zinc mining area in Yunnan, China. Environ Int. **31(5)**:755–762.
42. Saleh HM, Aglan RF, Mahmoud HH (2019) Ludwigia stolonifera for remediation of toxic metals from simulated wastewater. Chem Ecol **35**:164–178.
43. Galal TM, Gharib FA, Ghazi SM, Mansour KH. (2017a) . Phytostabilization of heavy metals by the emergent macrophyte *Vossia cuspidata* (Roxb.) Griff.: a phytoremediation approach. *Int J Phytoremed*. **19(11)**:992–999.
44. Lasat MM (2002) Phytoextraction of toxic metals: A review of biological mechanisms. *J Environ Qual* **31**:109–120.
45. Ademe EU. DG XVII (1995) (Altener Programme), The non-technical barriers liquid biofuels European network (used in engines and boilers). Information Leaflet, Ademe, Paris.
46. Abdelaal, M., Mashaly, I. A., Srour, D. S., Dakhil, M. A., El-Liethy, M. A., El-Keblawy, A. & El-Sherbeny, G. A. (2021). Phytoremediation perspectives of seven aquatic macrophytes for removal of heavy metals from polluted drains in the Nile Delta of Egypt. Biology, **10(6)**, 560.