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Remediation Potential of Select Wetland Plants

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ABSTRACT
Phytoremediation refers to the ability of certain plants to bioaccumulate, degrade, or render harmless the contaminants in soil, water, etc. Wetlands function as the kidneys of a landscape as plants in wetlands act as sinks by uptake of nutrients and heavy metals. The current study focuses on estimating the phytoremediation potential of some selected wetland plants. Plant samples were collected from inlets and outlets of Jakkur wetlands, Bengaluru, India on a weekly basis. The plants were identified using standard keys based on taxonomic literature. Plants identified were Typha *sp.,* Cyperus *sp.,* Ludwigia *sp.,* Pistia stratiotes, Polygonum *sp.,* Alternanthera philoxeroides *and* Spirodela *sp., which are perennial. Among these,* Typha *sp.,* Cyperus *sp.,* Pistia stratiotes *and* Spirodela *sp. are monocots, and* Ludwigia *sp.,* Polygonum *sp. and* Alternanthera philoxeroides *are dicots. These plants showed the uptake of the heavy metals viz., cadmium, zinc, nickel, copper, chromium and lead. During the first week, uptake of Cu and Zn was more by young* Typha *sp. at inlet and Cr was more at outlet of sampling. The uptake of Cu, Pb, Zn and Ni was 1.4, 9.0, 9.4 and 10.0 mg/kg respectively during the second week of sampling in young* Typha *sp. shoot. Also, the Pb and Zn uptake was 13.6 and 10.4 mg/kg respectively in the mature* Typha *sp. during the third week at outlet of sampling. Ni uptake was 4.0 mg/kg during the third week of sampling by mature* Typha *sp. at inlet. The uptake of Pb, Zn and Cd was 12.2, 23.0 and 1.4 mg/kg respectively during the fourth week of sampling in the mature* Typha *sp. at outlet. The uptake of Pb, Ni, Cr and Cd was 5.2, 2.4, 12 and 0.8 mg/kg respectively during the first week of sampling in the medium* Polygonum *sp. The uptake of Zn was 10.2 mg/kg during the second week in the mature* Alternanthera philoxeroides *at outlet of sampling. The uptake of Cr was 19.6 mg/kg during the third week was found to be more by mature* Alternanthera philoxeroides *at outlet of sampling. The uptake of Cu, Pb, Zn and Cr was 2.2, 9.8, 8.6 and 10.2 mg/kg respectively during the fourth week in young* Alternanthera philoxeroides *at inlet. Similarly, the uptake of Cr was 13.6 mg/kg at outlet during the second week in* Spirodela *sp. The uptake of Cu was 2.4 mg/kg during the third week in medium* Ludwigia *sp. at outlet.*

Keywords: *Phytoremediation, Macrophytes, Physiology, Wetland, Nutrients, Perennial*

Introduction

Metallic elements that have a high atomic weight, relatively high density and are toxic at low concentrations such as mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), thallium (Tl), lead (Pb), etc. are referred to as heavy metals. Applications of metals include domestic, agricultural, medical and technological with wider distribution in the environment. The potential effects on human health and the environment have been a concern, which necessitates suitable methods which can help in the remediation to minimise harmful effects. Soil and water are increasingly getting contaminated with heavy metals[1] due to sustained flow of untreated effluents which is damaging the environment. Sources of heavy metals in the environment are geogenic, industrial, agricultural, pharmaceutical, domestic effluent, etc. Escalated health concerns associated with environmental contamination due to heavy metals have necessitated remediation measures that are economical and technically feasible. Remediation is to avoid all such environmental damage. Remediation can be achieved with the help of various physico-chemical processes viz., ion-exchange, precipitation, reverse osmosis, ultrafiltration, flocculation, electro dialysis, etc. But these methods are costly, time-consuming, and are also not very effective[2].

Bioremediation is a viable and cost effective approach using microorganisms (bacteria, actinobacteria, fungi, algae and yeasts), plant residues and plants to remove heavy metals from waste water, industrial effluents, etc.[3,4]. Bioremediation is emerging as a green approach for the removal of heavy metals and other pollutants from contaminated land, water, etc.

Phytoremediation is one of the most eco-friendly, economical, simple and effective bioremediation options to remove heavy metals from waste water, industrial effluents, etc. In phytoremediation, the contaminated soils and water are treated *in-situ* with the help of plants[5]. Aquatic plants are of importance in this regard due to uptake mechanisms and rates of uptake of metals of these plant.[6,7].

Aquatic plants (macrophytes) are important component of wetlands[8], which have the special ability of adaption to the constant contact with surface water and groundwater[9]. Macrophytes have thin outer tissues and aerenchyma, through which air is distributed to the parts of plant below the surface of the water. Macrophytes vegetation has been used in wetlands to treat wastewater by uptake nutrients and heavy metals[10]. Macrophytes have a metabolic role in wastewater treatment due to their potential to release oxygen into the rhizosphere which helps in nitrification and direct uptake of nutrients[11] as in *Typha* spp. Which has a considerably high nutrient uptake capacity[12].

Aquatic macrophytes are appropriate for metal removal as they can tolerate adverse conditions and are easier to harvest[13]. Wetland plants are divided into emergent, submerged and floating types. The emergent plants are rooted in the soil with basal portions, and leaves, stems and reproductive organs are aerial[14]. The examples of emergent plants are *Phragmites australis*, *Typha domingensis*, *Typha latifolia*, *Phragmites karka*, *Juncus pallidus*, *Empodisma minus*, *Phalaris arundinacea*, *Scirpus cyperinus*, *Aster novae-angliae*, *Limonium carolinianum*, *Cephalanthus occidentalis* and *Rhizophora mangle*. Submerged plants are below the surface of water for their entire life cycle. The examples of submerged plants are *Ceratophyllum demersum*, *Vallisneria americana*, *Myriophyllum spicatum*, *Hydrilla verticillata*, *Heteranthera dubia*, etc. Submerged species provide more biomass for the uptake and sorption of the contaminants through phytoextraction. Submerged plants have the ability to accumulate metals in their tissues in comparison to rooted emergent plants. In floating plants, the leaves and stems float on the surface of water. The examples of floating plants include *Eichhornia crassipes*, *Pistia stratiotes*, *Salvinia herzogii*, *Wolffia columbiana*, *Lemna valdiviana*, *Nymphaea* spp., *Nuphar advena*, *Juncus effusus*, *Phyllanthus fluitans*, etc.[14].

The common aquatic plant species (*Typha latifolia*, *Myriophyllum exalbescens*, *Potamogeton epihydrus*, *Sparganium angustifolium*, *Myriophyllum spicatum* and *Sparganium multipedunculatum*) have been used for aluminium (Al) removal[15]. Macrophytes such as Parrot feather (*Myriophyllum aquaticum*), creeping primrose (*Ludwigia palustris*), and water mint (*Mentha* sp.) have been used for removal of iron (Fe), zinc (Zn), copper (Cu), and mercury (Hg) from water[16]. The *L. minor* has been used for removing copper (Cu) and cadmium (Cd) from contaminated soils[17].

Aim of the study:

The main aim of this research work was to assess the remediation potential of select macrophytes. This involved:

i) Weekly sampling of macrophytes
ii) Identification of macrophytes samples
iii) Assessment of remediation potential of selected wetland plants.

Materials and Methods

Study Area

Sampling of wetland plants

Wetland plants were sampled from inlets and outlets of Jakkur Lake, Bengaluru on a weekly basis (0.25 m^2 area). The plant samples were collected in triplicates. Collected macrophyte samples were washed, labelled and the plant species were identified using standard morphological keys based on taxonomic literature.[18]

Remediation potential of wetland plants

All the dried plant samples were powdered using mortar and pestle, sieved (1 mm) to get fine powders and labelled properly. The powdered plant sample (0.5 g) were acid digested[19] and analysed for six heavy metals viz., cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn) using reagent blanks and suitable standards using Flame Atomic Absorption Spectrophotometry (GBC Avanta version 1.31).

Results and Discussion

Diversity of the wetland plants

Total seven wetland plant species were collected from Jakkur Lake, Bengaluru. The identified plant species were *Typha* sp. (Figure 1), *Cyperus* sp. (Figure 2), *Ludwigia* sp. (Figure 3), *Pistia stratiotes* (Figure 4), *Polygonum* sp. (Figure 5), *Alternanthera philoxeroides* (Figure 6) and *Spirodela* sp. (Figure 7). Among these five are emergent (*Typha* sp., *Cyperus* sp., *Ludwigia* sp., *Alternanthera philoxeroides* and *Polygonum* sp.) and two are floating wetland plant species (*Spirodela* sp. and *Pistia stratiotes*).

Fig. 1. *Typha* sp.

Fig. 2. *Cyperus* sp.

Fig. 3. ***Ludwigia*** **sp.**

Fig. 4. ***Pistia stratiotes***

Fig. 5. ***Polygonum*** **sp.**

Fig. 6. ***Alternanthera philoxeroides***

Fig. 7. ***Spirodela* sp.**

Remediation potential of the wetland plants

Copper replaces other co-factors in key enzymes and disrupts photosynthetic activity and other cellular processes[20]. Lead toxicity causes swollen, bent, short and stubby roots[21]. Excess Zn will alter the physiological, ultra structural and biochemical parameters of the plants. Excess of Ni causes various physiological alterations and diverse toxicity symptoms such as chlorosis and necrosis in the plant species[22]. Copper concentration exceeding 20 mg/kg in the shoot is injurious, though copper is an essential element for growth[23]. The remediation potential of the wetland plants collected on weekly basis is represented in Tables 1, 2, 3 and 4 respectively.

Table 1. Uptake of heavy metals by the wetland plants (sampling done on 17/5/2017)

Plant samples	***Inlet**						***Outlet**					
	Heavy metals (mg/kg)						**Heavy metals (mg/kg)**					
	Cu	Pb	Zn	Ni	Cr	Cd	Cu	Pb	Zn	Ni	Cr	Cd
young *Typha* sp.	**17.2**	0.0	14.4	1.4	5.0	0.0	1.2	6.0	4.2	1.4	13.2	0.2
mature *Typha* sp.	-	-	-	-	-	-	0.0	3.2	3.2	0.6	10.0	0.0
young *Alternanthera philoxeroides*	0.0	0.0	2.8	2.0	0.6	0.0	0.0	7.6	3.0	**5.8**	10.8	0.0
medium *Polygonum* sp.	1.4	5.2	9.0	2.4	12.0	0.8	-	-	-	-	-	-
mature *Polygonum* sp.	0.8	0.0	3.2	0.2	8.8	0.2	-	-	-	-	-	-
medium *Ludwigia* sp.							0.6	8.4	6.4	**6.2**	10.6	0.6
mature *Pistia stratiotes*	-	-	-	-	-	-	2.6	8.2	7.0	**6.2**	9.6	0.2
Spirodela sp.	-	-	-	-	-	-	0.8	7.6	8.8	**6.8**	10.6	0.0
Normal range[24]	1-5	0.2-20	1-400	0.02-5	0.03-14	0.1-2.4						
Critical range[24]	5-30	30-300	100-400	10-100	5-30	5-30						
Threshold effect level[25]	35.7	18.0	123.0	35.0	37.3	0.596						

Table 2. Uptake of heavy metals by the wetland plants (sampling done on 30/5/2017)

Plant samples	*Inlet						*Outlet					
	Heavy metals (mg/kg)						Heavy metals (mg/kg)					
	Cu	Pb	Zn	Ni	Cr	Cd	Cu	Pb	Zn	Ni	Cr	Cd
young *Typha* sp. shoot	1.4	9.0	9.4	**10.4**	11.2	0.4	0.0	7.8	5.4	**5.8**	8.2	0.4
medium *Typha* sp. shoot	-	-	-	-	-	-	0.6	9.8	6.4	9.0	10.2	0.2
mature *Typha* sp. shoot	0.0	8.0	7.6	**10.0**	14.0	0.6	0.0	7.2	5.2	**8.0**	12.6	0.0
mature *Alternanthera philoxeroides*	-	-	-	-	-	-	0.6	8.8	10.2	**5.6**	10.0	0.4
mature *Pistia stratiotes*	-	-	-	-	-	-	1.2	5.0	8.8	**6.0**	7.0	1.6
Spirodela sp.	-	-	-	-	-	-	0.0	2.8	4.0	0.0	13.6	1.0
Normal range	1-5	0.2-20	1-400	0.02-5	0.03-14	0.1-2.4						
Critical range	5-30	30-300	100-400	10-100	5-30	5-30						
Threshold limit	35.7	18.0	123.0	35.0	37.3	0.596						

Table 3. Uptake of heavy metals by the wetland plants (sampling done on 6/6/2017)

Plant samples	*Inlet						*Outlet					
	Heavy metals (mg/kg)						Heavy metals (mg/kg)					
	Cu	Pb	Zn	Ni	Cr	Cd	Cu	Pb	Zn	Ni	Cr	Cd
medium *Typha* sp.	**14.4**	7.6	16.4	1.8	6.2	0.6	-	-	-	-	-	-
mature *Typha* sp.	2.0	4.6	5.2	4	6.0	0.8	1.0	13.6	10.4	0.0	2	0.2
mature *Alternanthera philoxeroides*	1.4	2.4	6.6	3.2	5.2	1.8	0.8	10.4	8.8	0.0	**19.6**	1.0
medium *Ludwigia* sp.	-	-	-	-	-	-	2.4	12.2	7.6	0.0	4.0	0.2
Normal range	1-5	0.2-20	1-400	0.02-5	0.03-14	0.1-2.4						
Critical range	5-30	30-300	100-400	10-100	5-30	5-30						
Threshold limit	35.7	18.0	123.0	35.0	37.3	0.596						

Metal uptake by wetland plants during the 1st week

The uptake of Cu by young *Typha* sp. from inlet exceeded the normal range and uptake of Ni by young *Alternanthera philoxeroides*, medium *Ludwigia* sp., mature *Pistia stratiotes* and *Spirodela* sp. from the outlet exceeded the normal range. (Table 1)

Metal uptake during the 2nd week

The uptake of Ni by young and mature *Typha* sp. shoot from inlet exceeded the normal range and uptake of Ni by young and mature *Typha* sp. shoot, mature *Alternanthera philoxeroides* and mature *Pistia stratiotes* from the outlet exceeded the normal range. (Table 2)

Table 4. Uptake of heavy metals by the wetland plants (sampling done on 13/6/2017)

Plant samples	*Inlet						*Outlet					
	Heavy metals (mg/kg)						Heavy metals (mg/kg)					
	Cu	Pb	Zn	Ni	Cr	Cd	Cu	Pb	Zn	Ni	Cr	Cd
medium *Typha* sp.	2.0	5.8	7.6	1.8	8.8	0.8	-	-	-	-	-	-
mature *Typha* sp.	1.6	5.2	6.8	2.2	9.0	0.6	1.8	12.2	23	3.0	5.4	1.4
young *Alternanthera philoxeroides*	2.2	9.8	8.6	1.4	10.2	0.2	-	-	-	-	-	-
medium *Alternanthera philoxeroides*	-	-	-	-	-	-	0.4	0.0	3.6	2.4	4.6	0.8
medium *Ludwigia* sp.	-	-	-	-	-	-	3.2	3.6	7.8	3.4	9.6	0.6
Normal range	1-5	0.2-20	1-400	0.02-5	0.03-14	0.1-2.4						
Critical range	5-30	30-300	100-400	10-100	5-30	5-30						
Threshold limit	35.7	18.0	123.0	35.0	37.3	0.596						

*Inlet and outlet are the sampling points at Jakkur Lake, Bengaluru.

C - Carbon; N - Nitrogen; P - Phosphorus; Cd - Cadmium; Cr - Chromium; Ni - Nickel; Zn - Zinc; Cu - Copper; Pb - Lead

Metal uptake during the 3rd week

The uptake of Cu by medium *Typha* sp. from inlet exceeded the normal range and uptake of Cr by mature *Alternanthera philoxeroides* from the outlet exceeded the normal range. (Table 3)

Metal uptake by wetland plants during the 4th week

The uptake of heavy metals by the macrophytes during the 4th week was within the normal range. (Table 4)

Wetland plants at storm water detention ponds have showed the ability for the uptake of nutrients and heavy metals[26]. *Eichhornia* sp. uptake heavy metals Pb, Cr, Zn, Mn, and Cu to a large extent from the wastewater[27]. *Ludwigia natans* is useful for remediation of Cd from contaminated water[28]. *Typha angustifolia* has been reported to assist remediation of various heavy metals (Cu, Pb, Ni, Fe, Mn, and Zn) and it has been found that the plant removes heavy metals from industrial wastewater containing metal, melanoidin, and phenol compounds[29]. *Spirodela* sp. has high uptake capacity of Cr, Zn and Pb[30]. The analyses highlights the use of plants for remediation as an environmental friendly approach because of their high efficiency in metal removal[31]. Removal of toxic metals by wetland plants viz., *Phragmites australis*, *Juncus effusus* and *Iris pseudacorus*[32]. *Carex pseudocyperus* and *C. riparia* have been reported to be effective for the removal of metals from water[33]. The heavy metal accumulation potential of wetland plants has been studied[34-38]. The spatial pattern of heavy metal accumulation in the sediments and macrophytes of Bellandur wetland, Bangalore, India show higher accumulation of all metals except for chromium in *Typha angustata*[35]. The bioremediation potential of aquatic macrophytes in Jakkur wetland, Bangalore, India is evident with the higher concentration of lead, zinc, nickel and chromium in *Typha angustatathan* at inlet. Nickel above normal range was observed in *Typha angustata* at inlet and in all plant species at outlet[36-38]. Similarly, there is a report on heavy metals in biotic and abiotic components of Varthur wetlands, Bangalore, India[37, 39]. The assessment of bioconcentration and translocation factors in macrophytes showed the select macrophytes are useful to remove heavy metals[37, 38].

Conclusions

The phytoremediation approach is an eco-friendly solution for the treatment of contaminated soils and water using plants. Common plants in wetlands such as *Typha* sp., *Cyperus* sp., *Ludwigia* sp., *Pistia stratiotes*, *Polygonum* sp., *Alternanthera philoxeroides* and *Spirodela* sp., have good remediation potential due to their metal uptake ability. Macrophytes have the ability for the uptake of heavy metals such as Cd, Pb, Zn, Ni, Cr and Cd, which will be the low cost option in the remediation of polluted soil and water. The uptake of heavy metals by the macrophytes during the fourth week was within the normal range suggesting that they can be used as fodder. Use of select local macrophyte species in the constructed wetland systems would aid in remediation through removal of contaminants (nutrients and heavy metals) from domestic and industrial wastewaters. Ensuring zero discharge from industries would be the best option toward ensuring heavy metals not getting into biotic food chain. Growing macrophytes in the flood plains of water bodies in rural area helps in treating agriculture run-off containing nutrients and heavy metals.

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