Phytoremediation Potential of Macrophytes of Urban Waterbodies in Central India

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Introduction

With increasing population and growing urbanization in India, wastewater generation is also increasing at a rapid pace. Lack of appropriate treatment facilities and inadequate policy planning at the local level has aggravated the issue and many rivers, lakes, wetlands, lakes and other waterbodies are polluted. Increased pollutants in waterways causes cultural eutrophication. Untreated municipal and partially treated sewage and other external inputs causes changes in surface water quality. Municipal sewage contains partially decomposed materials (inorganic and organics) and trace elements including cadmium (Cd), chromium (Cr), nickel (Ni), lead (Pb), copper (Cu), zinc (Zn), manganese (Mn) and iron (Fe). Waterbodies consisting of turbid heterogeneous liquid with persistent chemicals pose serious challenges due to water-borne diseases and health hazards.

Laxmi Taal in Jhansi, Bundelkhand (Uttar Pradesh) is a historical, previously rain-fed lake of about 32.52 hectares. Today, Laxmi Taal is encroached with an inflow of urban sewage and runoff from surrounding settlements, temples, gardens and farmland without undergoing any treatment or sedimentation. Monitoring and assessment of water contamination, especially heavy metal accumulation, is a serious concern, as inhabitants depend on the lake for vegetable irrigation, drinking water for livestock and recreation. The consequences of pollution on plants and animals has been extensively studied in lentic and lotic ecosystems.

Phytoremediation can be used as an alternative solution for heavy
metal remediation processes due to advantages as a cost-effective, efficient, environment- and eco-friendly technology based on the use of metal-accumulating plants.\textsuperscript{8,9} Acidic water aids the uptake of heavy metals by plants and the enrichment mechanisms are related to the surface area of the plant exposed to water.\textsuperscript{10} \textit{Eucalyptus camaldulensis}, \textit{Zea mays}, \textit{Potamogeton pectinatus} L., and \textit{Typha domingensis} are some of the best candidate species as hyperaccumulators for phytoremediation of heavy-metal contaminated soils and water.\textsuperscript{11-15} To appropriately plan remedial measures using vegetation for heavy metal removal, it is imperative to have adequate knowledge of the role played by detritus (sink/ source).\textsuperscript{16}

Phytoremediation concerns have gained considerable attention in warm sub-tropical to semi-arid regions. In water scarce areas, surface waterbodies are the main source of water for ‘B’ grade use. The present study aims to provide an assessment of water quality, level of heavy metals and a comparative phytoremediation potential of \textit{Typha angustifolia} and \textit{Echhornia crassipes}. These two species are commonly occurring pre-adopted, successful metal accumulators.\textsuperscript{17,18} An extensive study was carried out on their phytoremediation potential in high metal contamination areas. The present study assesses the metal accumulation potential of the species with lower concentrations of heavy metal contamination. The outcome of the study may be useful in planning for bioremediation and restoration measures for urban waterbodies.

**Methods**

Laxmi Taal is a shallow, fresh water urban lake in the city of Jhansi, spreading over an area of about 0.162 km\textsuperscript{2}. Laxmi Taal is located between latitude 25°27’20”- 25°27’50”N and longitude 78°35’20”- 78°35’45”E. With temples all along its boundary, it is a central part of the historical, cultural and recreational life of Jhansi city. It is approximately 32.52 hectares across with an average depth of 2.5 m and has a catchment area of 2370 hectares. The sewage carrying domestic wastewater of Jhansi city is dumped into Laxmi Taal through various nallas (channels), namely Kuberau nala, Kasai mandi nala, Laxmi gate nala, Jashiyana nala, Bangla ghat nala and Bludgeon nala. A large influx of people in the last few decades around the fringe of the lake has resulted in rapid deterioration of water quality. Increased inflow of untreated sewage, disposal of municipal solid wastes, excessive use of fertilizers and pesticides are some of the major problems facing the lake environment.

**Water sample collection and analysis**

The lake water samples were collected in precleaned, acid-treated high-
density 3L polythene bottles, in triplicate at approximately 30-day intervals from each sampling location in the study area. The sampling area was divided into four zones: inlet lake interface, depicted as blue arrows in Figure 1; lake boundary with macrophytes, depicted as red triangles; middle of lake, depicted by a blue circle; and lake outlet, depicted with a yellow arrow. The four water sampling sites were selected on the basis of input, regeneration capacity, open area and outlet. Water parameters were determined in the present study and the methods adopted are described below. The water samples were brought to the Institute of Environment and Development Studies, Bundelkhand University, Jhansi for analysis. Each group of samples was analyzed separately. The analysis work was carried out according to the procedures described below.

Temperature was measured with the help of thermometer, pH by a pH meter (Systronics, MK-VI), electrical conductivity (µscm⁻¹) by conductivity meter (Systronic, Serial No. 13613), turbidity (nephelometric turbidity units) was determined by a turbidity meter, water soluble ions (sodium (Na⁺) and potassium (K⁺) in the water sample were determined with the help of a flame photometer (Systronics-350), and calcium (Ca²⁺) was determined by the versenate titration method using ethylenediaminetetraacetic-disodium salt solution as chelate). Additionally, magnesium (Mg²⁺) in ppm, free carbon dioxide (CO₂), dissolved oxygen (mg L⁻¹), chemical oxygen demand (mg L⁻¹), carbonate (CO₃²⁻ mg L⁻¹), bicarbonate (HCO₃⁻ mg L⁻¹) and all other parameters were calculated by standard methods.¹⁹,²⁰

Plant sampling

A total of 30 samples of T. angustifolia and E. crassipus plants were collected from the study area and their root and

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| Parameters                        | Lake boundary | Middle of lake | Drainage inlet | Water channel outlet |
|-----------------------------------|---------------|----------------|----------------|----------------------|
| Temperature                       | 16.40         | 16.50          | 16.30          | 16.46                |
| Turbidity                         | 46.18         | 16.10          | 17.90          | 22.50                |
| pH                                | 7.64          | 7.74           | 7.743          | 7.46, 8.5            |
| Electrical conductivity           | 1751.16       | 1704.00        | 1547.33        | 1399.66              |
| Total solids                      | 1031.40       | 756.05         | 697.63         | 745.33               |
| Total dissolved solids            | 863.66        | 610.85         | 635.66         | 655.66, 500          |
| Total suspended solids            | 167.73        | 145.20         | 60.53          | 88.00                |
| Dissolved oxygen                  | 4.56          | 3.184          | 4.62           | 4.37, 6              |
| Biochemical oxygen demand         | 82.55         | 57.81          | 75.35          | 59.77, 2             |
| Chemical oxygen demand            | 179.00        | 159.71         | 124.33         | 110.66               |
| Hardness total                    | 216.00        | 199.71         | 186.67         | 288.67, 300          |
| Calcium hardness                  | 119.70        | 133.10         | 110.43         | 99.60                |
| Magnesium hardness                | 96.30         | 86.61          | 75.77          | 188.17               |
| Free CO₂                          | 79.20         | 52.49          | 71.60          | 73.73                |
| Carbonate                         | 81.62         | 76.26          | 77.25          | 74.00                |
| Bicarbonate                       | 115.19        | 114.73         | 135.46         | 128.14               |
| Sodium                            | 253.47        | 241.40         | 232.25         | 229.47               |
| Potassium                         | 58.52         | 50.44          | 41.55          | 40.70                |
| Calcium                           | 47.94         | 45.30          | 46.76          | 41.74, 80            |
| Magnesium                         | 23.41         | 21.06          | 18.98          | 22.55, 24            |
| Chloride                          | 210.16        | 223.75         | 180.57         | 243.34, 250          |

* Drinking water without conventional treatment but after disinfection (category-A).

Table 1 — Water Quality Results from Laxmi Taal
shoot system separated. Plant tissue samples were thoroughly washed with running tap water and rinsed with deionized water to remove any sediment particles attached to the plant surfaces. Plant tissue samples were oven dried at 70°C to constant weight, then the dried materials were ground into powder and preserved in paper bags in desiccators for subsequent analysis. The samples were digested following the procedure described by the AOAC official method 985.01.

Plant accumulation of metals was measured with the bioconcentration factor (BCF), the ratio of metal concentration in the root to wastewater. Translocation factor (TF) was estimated as the ratio of metal concentration in the shoot to the root.

**Results**

Analysis of pH is an important parameter in an examination of water quality. In the present study, the pH value varied between 7.463 and 7.743 during the summer season. It was found to be close to the prescribed limit of surface water quality category-A (pH 8.5). Turbidity ranged from 16.10 to 46.18 (nephelometric turbidity units). Turbidity is the measurement of scattered light at 90° in a water system and can be a hindrance to submerged plant growth.

Conductivity (µS cm⁻¹) varied from 1399.66 to 1751.16 in Laxmi Taal during the summer season (Table 1). Conductivity of water varies directly with the temperature and is proportional to dissolved mineral matter content. Dissolved oxygen (DO) is the most critical factor in determining water quality and reflects the physical and biological process prevailing in the water (nutrient load). In Laxmi Taal lake, the DO varied from 3.18 to 4.62 mg L⁻¹ during the summer season. The high DO content in the surface water may be a result of direct contact of the surface water layer which enhances the dissolution of oxygen in water. A minimum of 4 mg/L of DO should be maintained in water for healthy growth of biota. Chemical oxygen demand in Laxmi Taal was found in the range of 110.66 to 179.00 mg L⁻¹ during the summer season. The chemical oxygen demand was high at the drainage inlet due to the demand of oxygen from the degradation of waste.

Levels of free CO₂ were found to be 79.20, 52.49, 71.60, and 73.73 at sampling locations 1-4, respectively. These values were higher than the national surface water quality grade-D standard in India. This indicates intense oxidative activities in the water, which increases the level of free CO₂, similar to the levels of bicarbonate (114.73, 135.46, 115.19, 128.14) and carbonate levels (76.26, 77.25, 81.62 and 74.00). Levels of carbon in this lake were found to be unusually high.

Total solids reflect the suspended and dissolved materials in inorganic and organic forms. The levels in the form of total solids, total dissolved solids and total suspended solids were

| Surface water quality standard IS:2296 | Heavy metals under study µg/l |
|---------------------------------------|------------------------------|
| Study Sites                           | Mn   | Cu    | Zn    | Ni   | Pb    | Fe    |
| Boundary                              | 500  | 1500  | 15000 | 3000 | 100   | 300   |
| Middle                                | 23.87±3.5  | 269.70±49.84 | 18.50±6.10 | 114.62±17.60 | 1089.62±44.94 |
| Inlet                                 | 24.12±2.16  | 297.35±95.62 | 7.00±1.80  | 18.00±5.60  | 762.75±18.87 |
| Boundary                              | 141.75±8.2  | 455.50±61.98 | 44.37±4.10 | 40.87±6.00  | 1107.00±11.54 |
| Middle                                | 23.87±3.5  | 269.70±49.84 | 18.50±6.10 | 114.62±17.60 | 1089.62±44.94 |
| Outlet                                | 101.37±4.5  | 259.49±25.70 | 7.00±1.90  | 28.50±7.90  | 1026.87±24.95 |

Abbreviation: BDL, below detection limit; Cu, copper; Fe, iron; Mn, manganese; Ni, nickel; Pb, lead; Zn, zinc.

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**Table 2 — Heavy Metal Content in Laxmi Taal Across Study Sites**
collected. The total solid levels were 756.05, 697.63, 1031.40 and 745.33 mg/l. The increased levels in the present study may be due to increased mineralization and waste disposal activities. In this reflection, the concentrations of sodium, potassium, calcium, magnesium and chloride were at significant levels as shown in Table 1.

The BCF or enrichment coefficient is the ratio of concentration of element present in the surroundings to the plant tissue at the time of harvest as characterized by Equation 1.

Equation 1

$$BCF = \frac{P}{E}$$

where, $P$ represents the trace element concentration in plant tissues (mg/kg dry wt) and $E$ represents the trace element concentration in the water (mg/l). Higher BCF values indicate higher accumulations in plants.

All the sampling values of heavy metals were lower than the prescribed values for surface water quality (IS: 2296). The luxuriant growth of *Typha angustifolia* indicated favorable conditions. The enrichment coefficient study and translocation factor studies revealed that the bioconcentration factor was >1 in all of the cases. An enrichment coefficient of >1 indicates that the plant is an accumulator and an enrichment coefficient of <1 indicates an excluder plant. *Typha angustifolia* and *Echhornia crassipus* are accumulator plants. Heavy metals in decreasing sequence in *T. angustifolia* were found to be Ni>Pb>Fe>Zn>Cu in the root system, and in the shoot, accumulation of heavy metals was in the order of Fe>Ni>Pb> Zn>Cu. The TF value was found to be >1 in all cases except Mn, where concentration was found to be below detection limit.

### Table 3 — Heavy Metal Content (μg/l) in *Typha angustifolia* and *Echhornia crassipus* Grown in Laxmi Taal

| Name of the plant | Plant parts | Mn       | Cu       | Zn       | Ni       | Pb       | Fe       |
|-------------------|-------------|----------|----------|----------|----------|----------|----------|
| *T. angustifolia*  | Root        | 52.72±13.82 | 4.28±0.62 | 26.03±4.63 | 9.94±2.90 | 6.06±1.01 | 194.07±30.45 |
|                   | Shoot       | 934.33±105.23 | 8.98±1.69 | 97.58±5.22 | 7.71±0.61 | 29.47±3.37 | 1601.47±568.27 |
| *E. crassipus*    | Root        | 188.68±26.40 | 7.80±3.57 | 60.38±2.43 | 3.08±1.43 | 12.88±0.94 | 834.00±124.36 |
|                   | Shoot       | 854.25±316.28 | 62.50±17.53 | 238.10±76.36 | 12.85±8.42 | 25.15±1.20 | 946.40±459.34 |

Abbreviation: Cu, copper; Fe, iron; Mn, manganese; Ni, nickel; Pb, lead; Zn, zinc.

Discussion

Toxic metal contamination is increasing and has become a world-wide public health concern. Manganese, Cu, Zn, Ni, Pb and Fe compounds cause a variety of adverse human health effects. Copper toxicity leads to retention of Cu in the kidney. Copper begins to deposit in the liver, disrupting the liver’s ability to detoxify, further increasing Cu levels, and drastically affects the connective tissue, reproductive system, nervous system, adrenal function, and affects learning in newborn babies.

Zinc poisoning leads to gastrointestinal effects, such as abdominal pain, diarrhea and vomiting. In adverse cases, it may lead to sideroblastic anemia, hypochromic microcytic anemia and leukopenia that is primarily due to zinc-induced Cu deficiency. High levels of Zn are known to be cytotoxic and disrupt the homeostasis of other requisite elements.
Nickel allergy can show up in the form of contact dermatitis, lung fibrosis, nasal and lung cancers, cardiovascular and kidney diseases. \(^{33-37}\) Lead poisoning can be either acute or chronic and lead to diseases pertaining to the central nervous system and gastrointestinal tract in children and adults. \(^{38-40}\) Acute exposure can result in headache, loss of appetite, hypertension, renal dysfunction, sleep apnea, vertigo, arthritis, abdominal pain, fatigue and hallucinations. \(^{38}\) Iron is a significant nutrient for most living creatures since it acts as a cofactor for many important enzymes and proteins. However, if proper shielding is not there, it can catalyze reactions involving formation of radicals that can damage the biomolecules, tissues, cells and the whole organism. \(^{40,41}\)

Soil and water quality degradation and adverse effects on the human and animal health are largely attributed to industrial pollution, as they bioaccumulate in the food chain. \(^{42-43}\) Phytoremediation is an eco-friendly, low-cost, natural approach to clean up the environment. \(^{44,45}\)

| Metals | BCF shoot/root in lake water | BCF root/root in lake water | TF shoot/root | BCF shoot/root in lake water | BCF root/root in lake water | TF shoot/root |
|--------|-----------------------------|-----------------------------|------------|-----------------------------|-----------------------------|------------|
| Mn     | -                           | -                           | 0.00       | -                           | -                           | 0.00       |
| Cu     | 0.08                        | 0.04                        | 2.00       | 0.61                        | 0.12                        | 5.08       |
| Zn     | 0.37                        | 0.10                        | 3.70       | 0.91                        | 0.25                        | 3.64       |
| Ni     | 1.42                        | 1.1                         | 1.29       | 1.83                        | 0.24                        | 7.63       |
| Pb     | 1.03                        | 0.21                        | 4.90       | 0.88                        | 0.51                        | 1.73       |
| Fe     | 1.56                        | 0.18                        | 8.67       | 0.92                        | 0.88                        | 1.045      |

Abbreviation: BCF, bioconcentration factor; Cu, copper; Fe, iron; Mn, manganese; Ni, nickel; Pb, lead; TF, translocation factor; Zn, zinc.

Metal accumulating plant species (\textit{Typha angustifolia} and \textit{Eichornia crassipus}) concentrate toxic and heavy metals such as Mn, Cu, Zn, Pb, Ni and Fe up to 100-1000 times, compared to excluder plants. \(^{46,47}\) Thus, phytoremediation is highly recommended for removal of toxic heavy metals from waterbodies and soil so that they do not enter the food chain and result in disease in humans and animals.

**Conclusions**

The present study examined naturally growing vegetation in a domestic wastewater receiving lake, Laxmi Taal, in Jhansi, and indicated that parameters of wastewater in the lake were within the prescribed limit of water quality standard IS-2296 grade-D water. The bioconcentration factor study revealed that all of the values were approaching 1 or >1, thus \textit{T. angustifolia} and \textit{E. crassipus} are primary bioaccumulator plants.

Among the six heavy metals studied, Mn, Cu, Zn, Ni, Pb and Fe, the heavy metals TF value was found to be >1 in both \textit{T. angustifolia} and \textit{E. crassipus}. Heavy metals translocation from root to shoot was effective.

The heavy metal study revealed that accumulation of various metal ions by \textit{T. angustifolia} and \textit{E. crassipus} was higher in shoots than other parts of the plant. For all heavy metals, rhizofiltration and phytoextraction mechanisms have been found to be effective.

High levels of heavy metals have detrimental effects on the health of humans and animals. Monitoring of exposures and remedial measures are necessary to mitigate these effects. Phytoremediation has been found to be helpful in limiting the exposure of human beings and animals to the toxicity of water from lake Laxmi Taal, and in decreasing potential soil pollution, thus limiting the flow of these heavy metals further up the food chain. Phytoremediation by \textit{T. angustifolia} and \textit{E. crassipus} can be used effectively to help ensure waterbodies are free from toxic heavy metals.
metals dumped into waterways.

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