

PHYTOREMEDIATION OF WASTEWATER AND EFFLUENTS USING AQUATIC WEEDS

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Contamination of the aquatic environment by the heavy metals has become a serious concern in the developing world. Heavy metals unlike organic pollutants are the persistent in nature, therefore, tends to accumulate in the different components of the environment. These metals are released from a variety of sources such as mining, urban sewage, smelters, tanneries, textile industry and chemical industry. There are more than 300 distilleries in India, which produces approx. 3.5×10^{15} litres of waste effluent annually (AIDA, 2004) loaded with high BOD, COD values, phenolic, sulphates, phosphates, and various potentially toxic trace elements (Kumar and Chandra, 2004). 29000 million litres sewage is produced daily in India from class I and class II cities; while the remediation capacity of sewage treatment plants in our country is only 6000-7000 million litres per day.

In India we are following only primary treatment for the remediation of wastewater, in some cases secondary treatment. Textile wastewater also contains substantial pollution loads which increase the Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Suspended solids (TSS), Total Dissolved Solids (TDS) and heavy metals. Large areas of agricultural soils and aquatic environment are contaminated by trace element that mainly originates either from geogenic activities or agronomic practices, industrial emissions, or the application of waste effluents/sewage sludge.

Sewage water and its impact on water bodies

Sewage is human habitat base liquid waste, Sludge produced at time of treatment which causes

- ✓ Heavy metal accumulation
- ✓ Odour
- ✓ Exposure to pathogens
- ✓ Mosquito breeding in water bodies

At present 450 cities in India generate $17 \times 10^6 \text{ m}^3$ of raw sewage per day. Production of sludge is estimated to be around 1200 tonnes per day, potentiality is 4000 tonnes per day. Delhi city produces 600 million litres of waste water per day, 175 million litres untreated. Five major sewage treatment plants in Delhi produce 1200 million litres treated effluents per day – used to irrigated crop.

Table No. 1. Potential contaminants in wastewater

Contaminant	Concern
Pathogens	Human and soil health.
Nitrates	Groundwater pollution
Organics (chlorinated hydrocarbon pesticides), polychlorinated biphenyls (PCBs)	Deterioration of soil health Health hazard if directly ingested by animals.
Heavy metals:	
Copper, zinc, nickel and Lead	Accumulation in topsoil; toxic to plants at high levels.
Cadmium	taken up by plant and accumulates in leafy material
Mercury, chromium, selenium, arsenic	Little concern unless present in extremely high amounts.

Zinc (Zn) is considered as a serious environmental pollutant because of its non-degradability when discharged into a water body (Ineris, 2005). When present at elevated concentrations in aquatic systems (lakes, ponds, aqueous streams, etc.), Zn causes a variety of environmental problems, including loss of vegetation, groundwater contamination and metal toxicity in the food chain.

Why metals are toxic

- Oxidative stress: Redox active transition metals (e.g. Fe^{2+} , Cu^{2+}) produce free radicals
- Replace other essential metals in pigments and enzymes
- Some metal ions (Hg^{2+} , Cu^{2+}) react to thiol groups to interfere protein structure and functions
- (a) Land treatment Some metals occur as radioactive isotopes (^{238}U , ^{137}Cs etc.) to pose health risks.

The conventional methods for treating metal-contaminated waters are ions exchange, coagulation– flocculation, chemical precipitation and adsorption (Lenoble, 2003). These techniques are generally expensive especially if large volumes, low metal concentration and

high standard of cleaning are required (Miretzky *et al.*, 2004). In addition, these methods usually generate by-products (sludge, metal-rich waste, etc.) dangerous to our environment.

- (a) Land treatment
- (b) Thermal treatment
- (c) Ground water extraction and treatment
- (d) Chemical extraction
- (e) Ion exchange
- (f) Adsorption

Phytoremediation

There is a considerable potential for adopting other methods which show effectiveness and economic advantages. Phytoremediation has recently gained importance because of its cost-effectiveness, long-term applicability and ecological aspect (Weiss *et al.*, 2006; Rai, 2008). This technology is based on the ability of plants to absorb and accumulate metal contaminants in their tissues and eliminate high amount of these elements from water or groundwater. The process of phytoremediation requires metal absorption by roots and its translocation to shoots and leaves. The bio-removal process using aquatic plants contains two uptake processes: biosorption which is an initial fast, reversible, metal-binding process and bioaccumulation, a slow, irreversible, ion-sequestration step (Keskinan *et al.*, 2003).

A successful bio-sorption of Cd, Ni, Zn, Pb and Cu by dead biomass of aquatic macrophytes through ion exchange (Miretzky *et al.*, 2006), underlined a wide perspective for investigating bio-sorption from multi-metal solutions and studying interactive effects of other metal ions on ion-exchange process. Low cost and relatively higher efficiency of heavy metal removal from diluted solutions are among the leading advantages of bio-sorption, which could be easily adopted by developing countries like India for recycling/ treatment of heavy metal contaminated wastewater (Jang *et al.*, 2005).

Phytoremediation used for removing heavy metals and other pollutants by AMATS (aquatic macrophytes treatment systems) is a well-established environmental protective technique. The most common aquatic macrophytes being employed in wastewater treatment are water hyacinth (*Eichhorniacrassipes*), penny wort, water lettuce, water ferns and duck

weeds. Phytoremediation is use of green plants to remove pollutants from the environment or render them harmless. This concept has emerged from a broader philosophy of Bioremediation where besides plants, soil microorganisms are also used for amelioration of organic and inorganic contaminants. The presence of other aquatic photosynthetic autotrophs can deplete dissolved CO₂ in water during the period of high photosynthetic activity. This increases dissolved oxygen in the wastewater thus resulting in increased water pH.

Different approaches of phytoremediation

1. **Phytoextraction:** Accumulation of metals in shoot tissues followed by harvesting
2. **Phytodegradation:** Use of plants and microbes to degrade organic pollutants
3. **Rhizofiltration:** Use of plant roots to absorb and adsorb the heavy metals form water bodies
4. **Phytostabilization:** Reduction in leaching, runoff, soil erosion and bioavailability of heavy metals
5. **Phytovolatilization:** Use of plants to volatilize heavy metals

Aquatic plants and phytoremediation of water bodies

- ❖ Aquatic plants are chosen for absorb particular nutrient and to remove pathogens, metals and other contaminants from wastewater.
- ❖ Aquatic plants have been shown to be very effective as a secondary or tertiary state for water treatment and nutrient removal.

Table No. 2. Functions of plants in aquatic treatment

Plant parts	Functions
Roots and/or stem in water Column	Uptake of pollutants
	Surfaces on which bacteria grow
	Media for filtration and adsorption of solids
Stem and/or leaves at or above water surface	Absorbed sunlight, thus can prevent growth of suspended algae
	Reduce transfer of gases and heat between atmosphere and water

Common aquatic weeds used for phytoremediation

- Water hyacinth [*Eichhorniacrassipes (Mart.) Solms*]
- Penny wort (*Hydrocotylebonariensis*)

- Water lettuce (*Pistia stratiotes L.*)
- Water fern (*Salvinia auriculata Aublet*)
- Duck weed (*Lemna gibba L.*)

Water hyacinth as a major bioremediator

Water hyacinth:-

B. N.-*Eichhornia crassipes (Mart.) Solms*

Family- Pontederiaceae

Origin- Tropical South America

It is a most reproductive plants on earth thus it is considered the world's worst aquatic plant. Water hyacinth has the unique property to accumulate heavy metals such as cadmium, copper, lead and zinc in the root tissue of the plant. In terms of bacterial reduction by water hyacinth-based systems, two theories exist. First, bacteria are trapped in the rhizosphere of the macrophytes with TSS, and second, water hyacinth may secrete chemical substances having bacteriostatic effects. The extensive removal of heavy metals by water hyacinth may be due to extensive adventitious root system, which absorbs these toxic substances from wastewaters (Mandi, 1994). Water hyacinth forms dense mats on the water surface of the non-saline part of the estuary and this is much common during the wet season.

Table No. 3. Characteristics of a typical wastewater: (Mahmood *et al.*, 2005)

Sample No.	Parameters	Range in wastewater (mg/L)
1	pH	5.5-10.5
2	COD	350-700
3	BOD	150-300
4	Total dissolved salts	1500-2200
5	Total suspended salts	200-1100
6	Sulphides	5-20
7	Chlorides	200-500
8	Chromium	2-5
9	Zinc	3-6
10	Copper	2-6
11	Oil and grease	10-50
12	Sulphates	500-700
13	Sodium	400-600

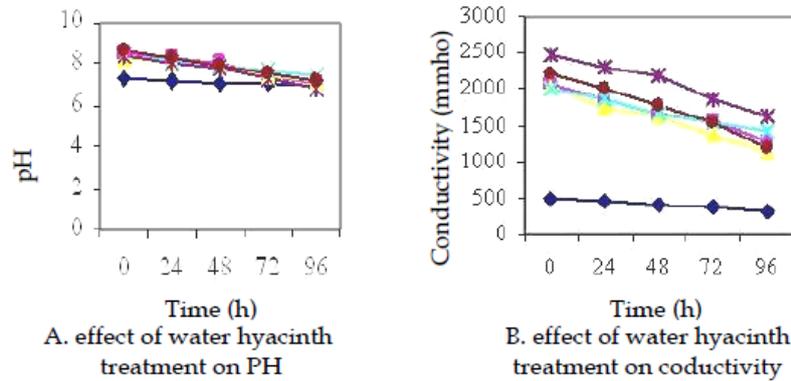


Figure 1. Effect of water hyacinth on pH and conductivity of wastewater (Mahmood *et al.*, 2005)

Mahmood and his co-workers collected effluents from five different textile industries viz. (1) M/S asma dying and printing industries, (2) Cebee industries, (3) Comfort wear knit, (4) Al-Saeed dying nad printing industries and (5) Kamran textiles. And reported the effect of water hyacinth treatment of wastewater in relation to pH and conductivity and they reported a considerable reduction in the conductivity and pH of the wastewater. The maximum reduction in the conductivity was obtained for wastes from CEBEE Textile Industries (55.71%). It can be interpreted that the reduction in pH and conductivity might be due to absorption of pollutants by plant (Figure 1) (Mahmood *et al.*, 2005).

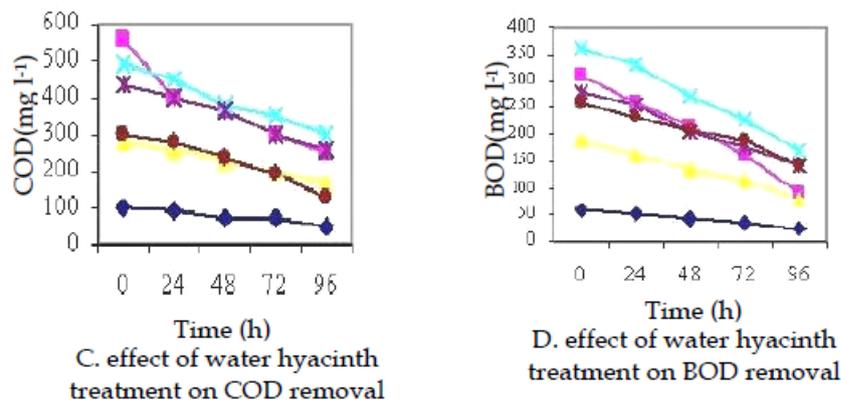


Figure 2. Effect of water hyacinth treatment on BOD and COD of wastewater

Water hyacinth treatment shows a significant reduction in biological oxygen demand (BOD) and chemical oxygen demand (COD) which ranging from 40-70 % is very encouraging performance for any kind of industrial waste after only 96 hours of treatment. The presence of plants in wastewater can deplete dissolved CO₂ during the period of high

photosynthetic activity. This photo-synthetic activity increases the dissolved oxygen of water, thus creating aerobic conditions in wastewater which favor the aerobic bacterial activity to reduce the BOD and COD. The maximum reduction (70%) was obtained for wastewater collected from CEBEE textiles (Figure 2).

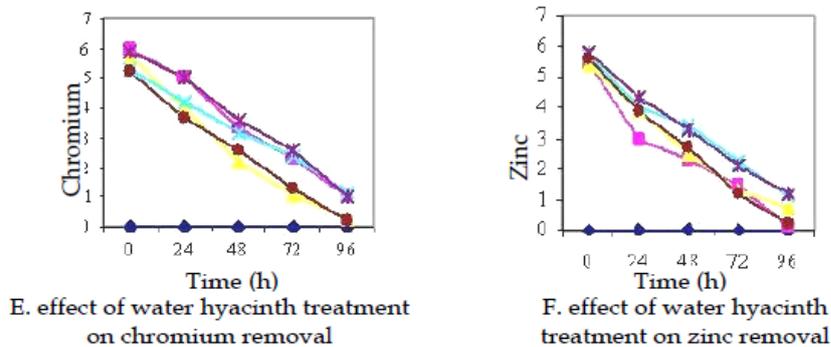


Figure 3. Effect of water hyacinth treatment on Chromium and Zinc concentration in wastewater (Mahmood *et al.*, 2005)

Water hyacinth has tremendous potential to remove heavy metals from wastewater, treatment of textile wastes with water hyacinth resulted 78.30-94.78% reduction in chromium, 79.34-96.88 % in zinc and 78.30-94.44 % reduction in copper. The maximum reduction of chromium and zinc occurred from Al-Saeed Textiles while the maximum reduction for copper was noted in the wastewater from Cebee Textiles (Figure 3).

Tripathi and his co-workers reported the per cent removal of heavy metals at different concentrations of these metals and they reported that metal removal percentages were highest at 2 mg l⁻¹ for all the three macrophytes for most of the times. Removal percentage decreases for the metals at 5.0 mg l⁻¹ with few exceptions. The heavy metals removed by *E. crassipes* were very high and ranged between 77% and 95% in 12 days incubation period (Table 4). The highest removal percentage at 1.0 mg l⁻¹ was shown by *E. crassipes* (92) followed by *P. stratiotes* (91) for Zn whereas this was increased at 2.0 mg l⁻¹ and it was maximum for *E. crassipes* and *P. stratiotes* as 95% for Fe. Removal efficiencies reached highest at 2.0 mg L⁻¹ for all the metals except Cu which has shown slightly increased removal percentage at 5.0 mg L⁻¹

Table No. 4. Removal of heavy metals through three aquatic macrophytes (Tripathi *et al.*, 2008)

Heavy metals	Concentrations (mg l ⁻¹)	% Removal		
		<i>Pistia stratiotes</i>	<i>Spirodela polyrrhiza</i>	<i>Eichhornia crassipes</i>
Fe	1	87	83.5	85.7
	2	95	81	90.1
	5	90	77.5	78.6
Cu	1	96	91	95
	2	87	83	89
	5	88	76	86
Cd	1	78	63	81
	2	82	71	85
	5	70	65	77
Cr	1	81	83	85
	2	75	75	89
	5	70	62	81
Zn	1	90	90	92
	2	92	92	95
	5	82	82	85

Table No. 5. Heavy metal concentration in macrophytes and impacts on biochemical parameters (Tripathi *et al.*, 2008)

	Concentration (mg/l)	Chlorophyll (mg g ⁻¹)	Protein (mg g ⁻¹)	Sugar (mg g ⁻¹)
<i>Eichhornia crassipes</i>				
Leaves	0	10.31	113.3	40.12
	1	8.67	98.4	28.5
	2	6.2	81	20.4
	5	4.17	65.25	16.3
Roots	0	—	77.26	13.36
	1	—	67.34	8.16
	2	—	61.24	7.26
	5	—	54.23	2.16
<i>Spirodela polyrrhiza</i>				
Leaves	0	2.67	51.42	26.1
	1	2.52	43.71	17.2
	2	2.1	27.11	10.5
	5	1.6	24.33	6.8
Roots	0	—	16.8	9.8
	1	—	11.2	6.3
	2	—	9.3	2.1
	5	—	4.2	1.7
<i>Pistia stratiotes</i>				
Leaves	0	7.12	67	11.26
	1	5.63	52	9.8
	2	4.12	48	6.5
	5	3.06	21	3.3
Roots	0	—	21.3	9.7
	1	—	17.2	6.6
	2	—	14.5	5.4
	5	—	6.7	3.12

Heavy metal accumulation in aquatic macrophytes is known to produce significant physiological and biochemical responses towards the growth of roots, stems and leaves (Shankers *et al.*, 2005). These parameters decreased in plant tissues after 15 days incubation period. Chlorophyll content decrease from 10.31 mg g⁻¹ to 4.17 mg g⁻¹ in *E. crassipes*, 2.67 mg g⁻¹ to 1.6 in *P. stratiotes* and 7.12 to 3.06 mg g⁻¹ in *S. polyrrhiza*. The reduction of chlorophyll content in macrophytes may be attributed to inhibition of chlorophyll synthesis which results in the loss of photosynthetic activity. The decrease in sugar content may be associated with reduced photochemical activities and chlorophyll formation. Loss of sugar

formation may also be due to the conversion of sugar into energy when the plants were stressed (Table 5).

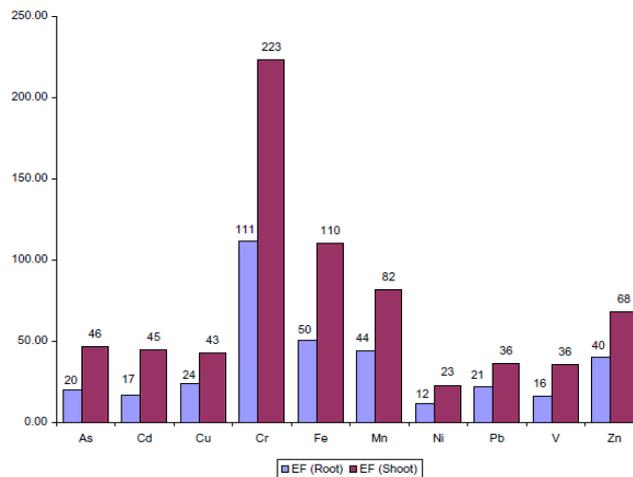


Figure 4. Enrichment factor of the metals from the coastal to root and shoot of water hyacinth (Bamidele *et al.*, 2009)

Bamidele and his co-workers reported the enrichment factor of the water hyacinth which is the measurement of the degree of metal transfer from water to the plant roots and shoots for different metals. They reported that the degree of enrichment of the shoot is higher than that of the root for the ten metals which indicates that the metals are transferred into the upper part of the plant (Figure 4). The least EF observed in the study was 12 which corresponded to Ni metal transfer to the plant root. Cr is the most transferred metal into both the root and the shoot followed by Fe, Mn and Zn in the decreasing order. phytoextraction of metals depends on factors such as the degree of site contamination, plant's ability to intercept, absorb and accumulate metals in shoots, metal availability for uptake into roots governed by its dissolution into aqueous phase and ultimately the interaction between the plant habitat.

However, the high EF indicates the plant's ability to intercept, absorb and accumulate metals in both its root and shoot; the high bioavailability of the metals that are already in aqueous phase for easy uptake by the plant and favourable interaction between the metals, the plant and the aquatic habitat where the plant grows. The uptake rate of the plant for metals was predicted at approximately 0.5 $\mu\text{g}/\text{day}$ using the predictive mathematical model which relates transpiration stream concentration factor (TSCF) (Figure 4).

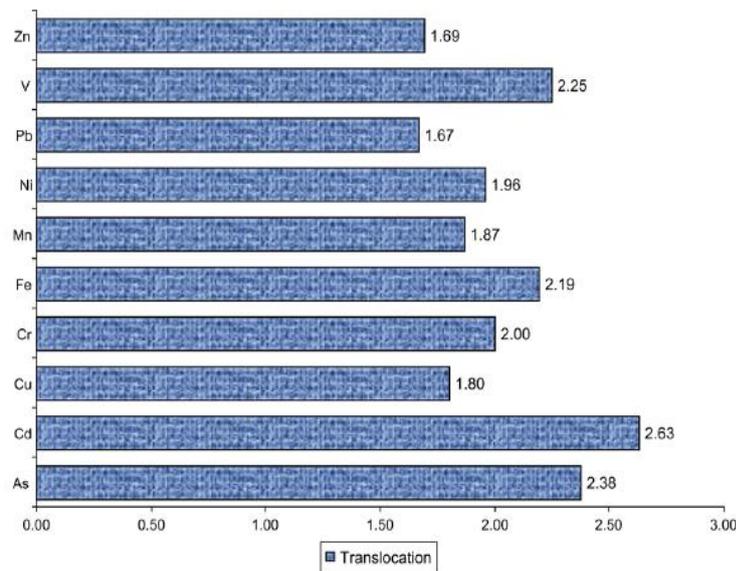
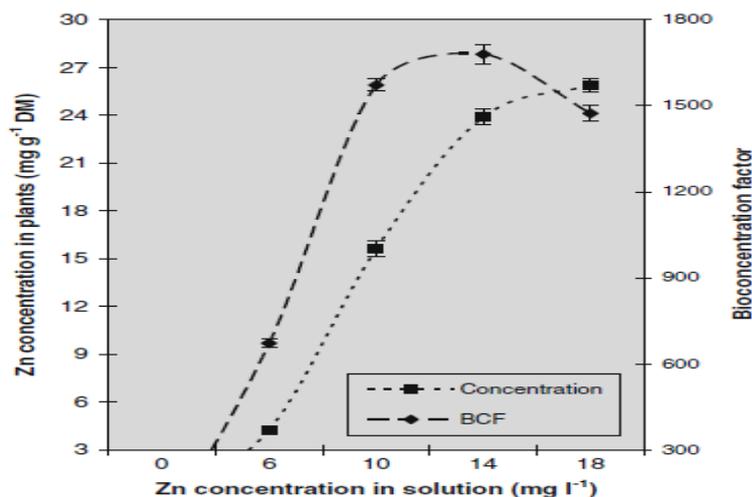


Figure 5. Translocation of metals from root to shoot of water hyacinth (Bamidele *et al.*, 2009)

Translocation of the metals from the root to the plant shoots which must be above 1 if the plant has to be an effective phytoremediator. The translocation of the metals into the shoot is higher than that into the root which implies that the plant has a high capacity to absorb the metals in the stalk and the leaves than the root. The translocation of Cd is ranked highest followed by those of As, V, Fe, Cr in the decreasing order (Figure 5).



Graph 1. Zinc concentration in solution and its accumulation in *Lemnagibba* (Khellaf and Zerdaoui, 2009)

Khellaf and Zerdaoui reported The Zn concentration in *L. gibba* increased with increasing initial concentration in the Coïc solution. The metal amount accumulated in duckweed biomass was 4.23, 15.62, 23.88 and 25.81 mg g⁻¹ DM when the medium was supplied with 6.30, 9.92, 14.23 and 17.57 mg g⁻¹ of Zn, respectively (Graph 1). To quantify metal accumulation in plant biomass, the bio concentration factor (BCF) is more significant than the amount accumulated in plants since it provides an index of the ability of the plants to accumulate metal element with respect to the element concentration in water.

Conclusions

- ❖ The heavy metals show a greater affinity towards bioaccumulation by aquatic weeds, which lead to filtration of metallic contaminants from wastewater.
- ❖ The maintaining of proper density of macrophytes in the water bodies by way of harvesting followed by disposal may regulate heavy metal contamination of water bodies without introducing any foreign chemicals.
- ❖ *Eichhorniacrassipes* has high affinity to accumulate metals in both root and shoot in a high degree and also to be capable of transferring the metals absorbed into the shoot to give higher translocation factors.
- ❖ Plants having large biomass on the water course with broad leaves and not consumed by animal/human being could serve as an effective phytoremediation.

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