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Biological Remediation of Hazardous Pollutants Using Water Hyacinth – A Review

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Abstract: Water hyacinth (*Eichhornia crassipes*, family *Pontederiaceae*) is extremely productive plant present on the earth and could be considered as the world's worst aquatic plant and hence known as "Blue Devil". It is a high water consumer plant, and has a horrible dense mats of floating green blocks. Water hyacinth causes numerous negative effects on aquatic ecosystems; as well as boat traffic, offset swimming, fishing. Moreover it covers the water column and submerged plants from sunlight. On contrary, water hyacinth is considered a candidate plant for tremendous advantages in economical industries and contaminated water treatment. Other than, it has wide acceptance in phytoremediation and it is considered as a good agent for bioaccumulation of heavy metals. In the same manner, it can be used in cleaning water streams from radionuclides. This article will present state-of-the art research and experimentation in the development of new concept and new applications of water hyacinth as a biological remediating agent for hazardous pollutants including radioactive wastes. This review will cover remediation application of water hyacinth and testing of new approaches developed in laboratories that could be more attractive for readers including students, chemists, molecular scientists and industrial researchers.

Keywords: Phytoremediation; water hyacinth; Hazardous pollutants; Heavy metals, Radionuclides.

1. Introduction

Toxic heavy metals in aquatic ecosystems, resulting from effluents containing untreated metal into water, is one of the most important environmental concerns for study. Heavy metals are toxic pollutants released into the surface and ground water as a result of different activities such as industries, mining, and agriculture and could associate with several health effects. Based on its effects on human beings and other aquatic organisms, a number of technologies can be used to remove heavy metals from contaminated water such as filtration, chemical precipitation, ion-exchange, adsorption, solvent extraction, electrodialysis and reverse-osmosis. However, these methods are not efficient in removing low heavy metals concentrations, can be relatively expensive and may fail to achieve legal limits [1].

Appropriate treatment of the heavy metals from the polluted water is of high importance. Phytoremediation, i.e. removal of metals through plants offers an eco-friendly and cost effective methodology for the treatment of heavy metals from contaminated water. Phytoremediation is more attractive sort of environmental sciences to investigate many advantages of environmental friendliness, cost effectiveness and the possibility of harvesting the plants for the extraction of absorbed hazardous contaminants that cannot be easily biodegraded such as heavy metals [2, 3].

Numerous plants like *Eichhornia crassipes* have been reported to be as a particulate contamination phytoremediator.

Among various plant groups used for phytoremediation, aquatic macrophytes attain the most important position and was seen as practical, proficient, novel, eco-friendly agent, still in its initial improvement stages and full scale applications are still constrained [4]. The aquatic plants are free-floating aquatic, entire root system of these plants is submerged in water. These species have a great potential to take up heavy metals from surroundings water and accumulate it inside their plant body [5].

Aquatic plants are used as a practical and effective method to remove toxic elements from secondary treated municipal wastewater. Water hyacinth (Eichhornia crassipes, family Pontederiaceae) a rooted macrophyte, known to grow profusely in polluted water bodies, eutrophic lakes and has great potential for the heavy metal accumulation. This species has been an important choice for phytoremediation of heavy metals from waste water due to its several advantages over other species [6-8]. Water hyacinth has gained wide acceptance as a phytoremediating agent. It is exceptionally good at taking up and accumulating heavy metals. Moreover, water hyacinth be used for remediating water from radionuclides. The radionuclide accumulation by water hyacinth occurs both through assimilation by the plant and through sedimentation of radionuclide-containing suspended material on the plant's roots. Current study is aimed at wider application of water hyacinth to the cleanup of small rivers, reservoirs, and industrials effluents.

2. Metal Toxicity and Plant-Metal Uptake

Plants have the capability to contain essential metals (Ca, Cu, Fe, K, Co, Mg, Na, Mn, Mo, Ni, Se, V and Zn) from the soil/aqueous medium. Different concentrations of these element have needed to develop and grow. This need compels plants to accumulate non-essential metals of no known biological benefits (Hg, Pb, Pd, Pt, Sb, Al, As, Au, Cd, Cr, Te, Tl and U) [9].

To illustrate the extraction and accumulation of metals from soil solution, the metal must pass from the soil solution to the surface of the root before passing into the plant. This could be happened either be a passive way (metal ions move through the porous cell wall of the root cells) or an active way (metal ions move through the cells of the root). The active way requires that the metal ions traverse the plasmalemma [10]. Phytoremediation as a cost effective, and has aesthetic advantages and long term applicability is a promising technology for cleaning up contaminated zone. It is effective for application at sites with shallow contamination of organic, nutrient or metal pollutants that are responsible to one of the five mechanisms; phytotransformation, bioremediation, phytostabilization, rhizosphere rhizofiltration and phytoextraction [11].

3. Accumulation of Chromium and Zinc [12]

Water hyacinth with approximately the same size and weight, 7–8 weeks old were used to remove Cr and Zn at different concentrations (1.0, 5.0, 10.0 and 20.0 mgl^{-1}).

The initial and final concentrations of heavy metals within the plants and removal efficiencies of water hyacinth at different concentrations of metals are shown in Table 1.

Table-1. Initial and final concentrations and removal % of Zn and Cr by water hyacinth [12]

Initial concentration, mg l^{-1}	Zn concentration in plants, mg g^{-1} (dry weight)	Zn removal, %	Cr concentration in plants, mg g^{-1} (dry weight)	Cr removal, %
1	0.88	94	0.10	84
5	1.22	91	1.13	79
10	1.83	95	1.41	72
20	2.32	88	1.71	63

It could be stated that with increasing metal concentration water hyacinth was able to remove and accumulate high amount of heavy metals.

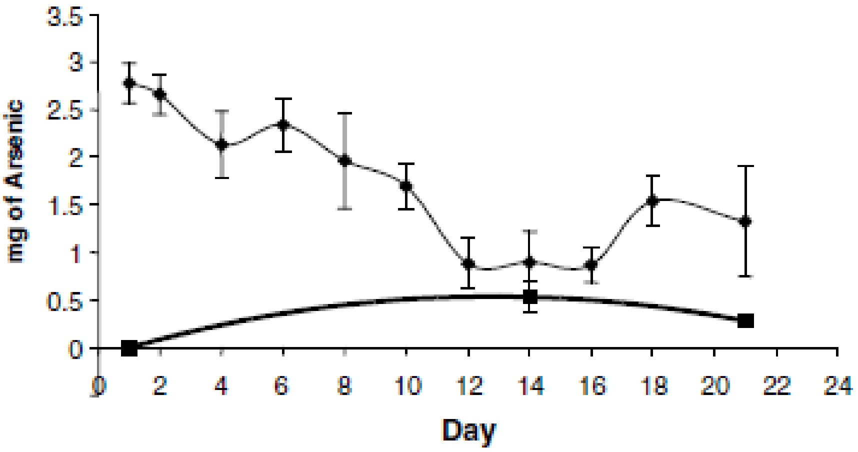
The removal efficiencies for Cr and Zn varied with varying concentration of these two heavy metals. Water hyacinth as a good accumulator has accumulated Zn and Cr up to 3.542 and 2.412 mgg^{-1} at metal concentration of 10 mgl^{-1} after 11 days of exposure. This plant has successfully removed up to 84% of Cr and 94% of Zn. The root of water hyacinth was the most effective part of all the plant tissues to accumulate Zn during the treatment process. Accumulation of chromium at the concentration of 10.0 and 20.0mgl^{-1} is associated with yellowing of the leaves, growth retardation and chlorosis as a morphological symptoms of toxicity while no toxic symptoms was noticed at all the studied concentrations of Zn. On the basis of results water hyacinth can be recommended for the removal of Cr and Zn from waste water.

4. Arsenic Removal from Waters by Bioremediation with Water Hyacinth [13]

Several studies suggest that it may be possible to use water hyacinths effectively to remove the arsenic from the drinking water that is poisoning the people. The arsenic is one of the most toxic elements that could be found in waters. It could be found in water as the result of the dissolution of minerals from volcanic or sedimentary rocks as well from the dilution of geothermal waters. It is also employed in the manufacture of lasers, semiconductors, in the glass industry, pharmaceutical products, and pigments among other uses. The arsenic masses in the tissue and water for the water hyacinth are shown in Fig. 1. The minimal amount of the element in water is found at the 14th day of the experiment and it is in agreement with the maximum concentration in tissue. After the 14th day there was a release of the element to water, as consequence of tissue death in plant. A higher accumulation in the tissue of the water hyacinth was observed.

The arsenic absorbed mass and removal rate of the water hyacinth suggest that this plant has a better capability for the removal of the element during the first 14 days. The species must be harvested every 15th days in order to avoid the release of the arsenic to the water.

Fig-1. As in wat◇( ) and foliar tissue () as function of time for water hyacinth [13]



In spite of the fact that, the high biomass production of the plant leads to a significantly high removal efficiency of the arsenic from contaminated water (Table 2). The environmental variables were more adequate for the water hyacinth as deduced from the agronomical behavior and in agreement to the optimal climatic condition and consequently, water hyacinth can grow up at temperatures till 37 ^{o}C.

The removal efficiency of water hyacinth was high due to the biomass production and the more favorable climatic conditions. This specie represents a reliable alternative for arsenic bioremediation in waters.

Table-2. Bioaccumulation, removal rate and removal % for water hyacinth [13]

mg of As/kg n = 5	mg of As/ha d n = 5	Removal % n = 5
1.8 ± 0.5	600 ± 140	18 ± 5

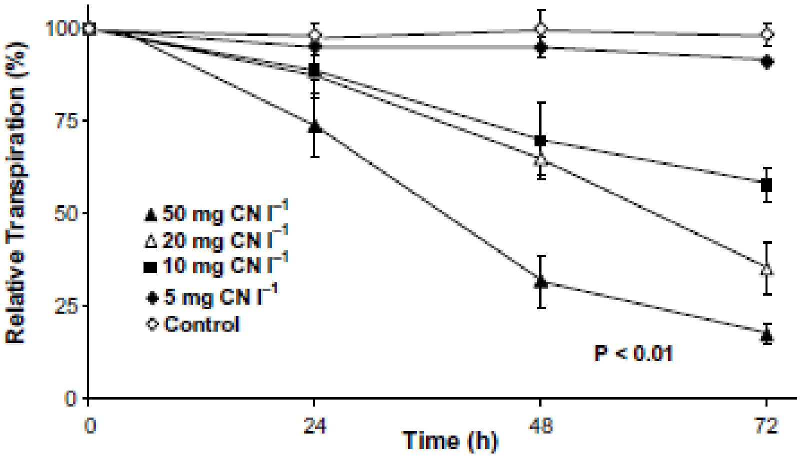
A comprehensive study on the arsenic removal from water by water hyacinth was performed by [13], and the results showed that it had a removal rate of 600 mg arsenic ha^{-1} d^{-1} under field condition and a removal recovery of 18% under laboratory conditions. The removal efficiency of water hyacinth was higher due to its high biomass production and favorable climatic conditions. Arsenic removal efficiency of water hyacinth had the highest removal efficiency (80%) [14]. Water hyacinth represents a reliable alternative for arsenic bioremediation in aquatic system even though the plant may cause severe water management problems because of its huge vegetative reproduction and high growth rate [15]. So, the use of water hyacinth in phytoremediation technology should be considered carefully.

5. Cyanide Phytoremediation by Water Hyacinths [16]

Ebel et al., demonstrated a high tolerance of water hyacinth to cyanide and fast removal of free cyanide in solution, either alone or in conjunction with associated microorganisms. Cyanide in the effluents from the latter mines could possibly be removed by the water hyacinth because of its high biomass production, wide distribution, and tolerance to cyanide (CN) and metals.

In the cyanide toxicity experiments, cyanide decreased the relative transpiration of water hyacinth; higher concentrations led to lower transpiration (Fig. 2).

Fig-2. Relative transpiration of water hyacinth growing in hydroponic solution supplied with cyanide at different concentrations [16].



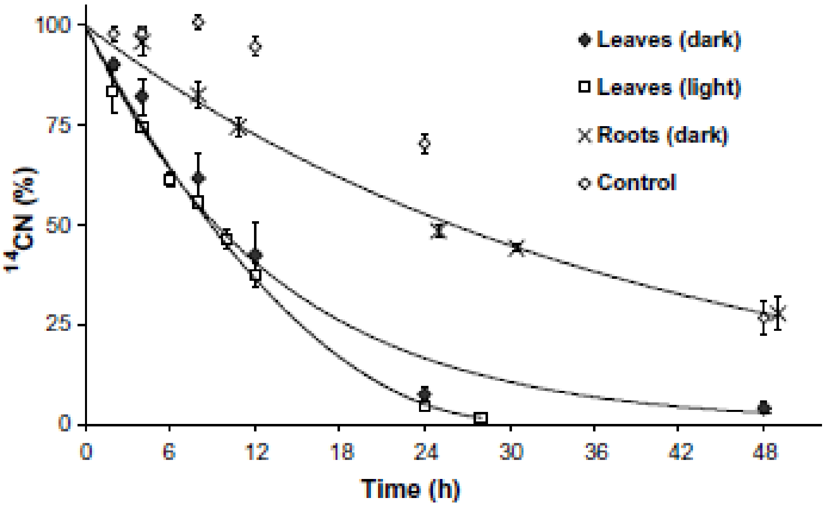
At the lowest concentration (5 mg L^{-1}), transpiration was only slightly reduced and the plants survived without any morphological changes. At higher concentrations, the plants developed chlorosis and the leaves faded after 48 h.

All plants at 50 mg CN L^{-1} and 60% of the plants at 20 mg CN L^{-1} died during the experiment; plants exposed to 10 mg CN L^{-1} survived, but lost about 50% of their leaves by desiccation.

The relative transpiration of the control plants did not change from the initial relative transpiration, illustrating the fitness of the plant in these unusual surroundings.

Spectrophotometric analysis indicated that cyanide at 5.8 and 10 mg L^{-1} was completely eliminated after 23–32 h. Metabolism of K^{14}CN was measured in batch systems with leaf and root cuttings. Leaf cuttings removed about 40% of the radioactivity from solution after 28 h and 10% was converted to $^{14}CO_2$; root cuttings converted 25% into $^{14}CO_2$ after 48 h but only absorbed 12% in their tissues (Fig. 3).

Fig-3. ^{14}CN removal in closed batch systems with root and leaf cuttings of water hyacinth [16]. Removal of cadmium and zinc by water hyacinth [17]



Cadmium (Cd) is one of the most toxic heavy metals and is considered non-essential for living organisms. Unlike Cd, zinc (Zn) is an essential and beneficial element for human bodies and plants. The phytoaccumulation of heavy metals, Cd and Zn, by water hyacinth was studied by [18].

In general, there were increases in metal accumulation in shoots and roots when metal concentration and exposure times were increased. For Cd, control and plants treated with 2 and 4 mg/L showed a significant difference in metal accumulation (Fig 4). There was a significant difference in Cd accumulation with the passage of time at all concentrations except for 0 and 0.5 mg/L. For Zn, significant differences between control and treated plants were found at all metal concentrations (Fig 5). There was a significant difference in accumulation with the passage of time at all concentrations. Plants treated with 4 mg/L of Cd on day 8 accumulated the highest level of metal in shoots (113.2 mg/kg; Fig 4A) and in roots (2044 mg/kg; Fig 4B); while plants treated with 40 mg/L of Zn on day 4 accumulated the highest level of metal in shoots (1926.7 mg/kg; Fig 5A), and in roots (9652.1 mg/kg; Fig 5B).

The maximum values of bioconcentration factor (BCF) for Cd and Zn were 622.3 and 788.9, respectively, suggesting that water hyacinth was a moderate accumulator of Cd and Zn and could be used to treat water contaminated with low Cd and Zn concentrations.

Fig-4. The accumulation of Cd in shoots (A) and roots (B) of water hyacinth [17]

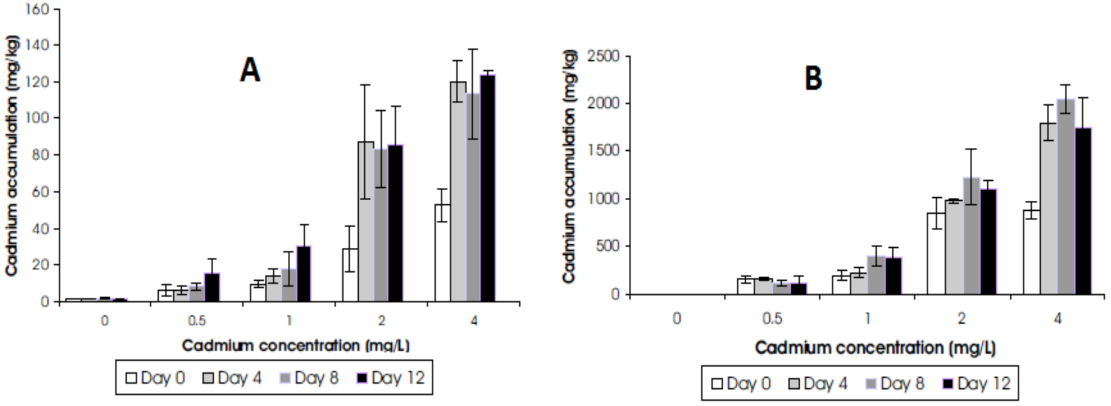
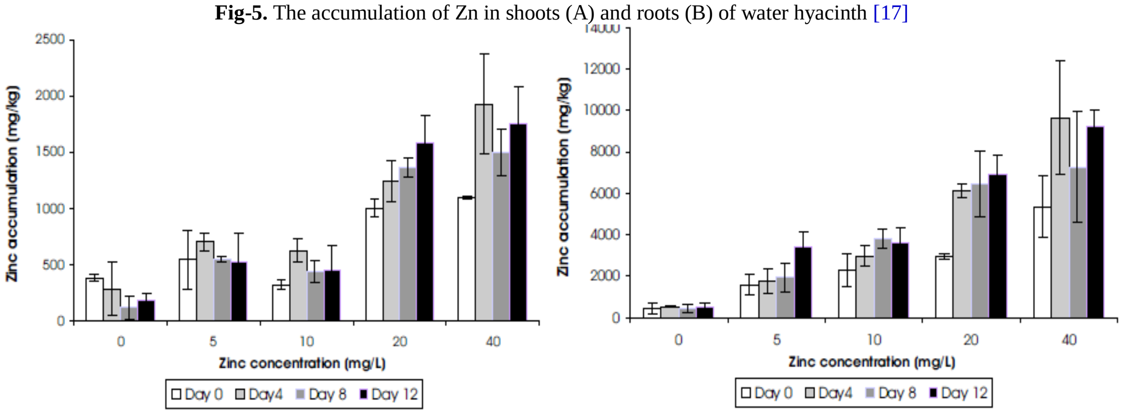


Fig-5. The accumulation of Zn in shoots (A) and roots (B) of water hyacinth [17]



6. The Uptake of Platinum Metals by the Water Hyacinth [19]

The biological effects of the platinum group metals on plants have been studied by Farago and Parsons and founded that water hyacinths are capable of recovering platinum group metals even from dilute solution though to varying degrees depending on the metal:

$$\xrightarrow[\text{Decreasing \% recovery at the 0.05 ppm level}]{Pt^{2+} > Pd^{2+} > Os^{4+} \approx Ru^{3+} > Ir^{3+} \approx Rh^{3+}}$$

Platinum, when applied as the antitumor complex cis- $[Pt(NH_3)_2C1_2]$ at low levels, some 47.9% of the platinum found in the leaves of water hyacinth was associated with α-cellulose and lignin; 16.1% was removed by the proteolytic enzyme pronase and 20.8% found with water soluble pectates. A similar distribution of platinum was found in the floats of water hyacinth. In the roots of treated plants, the values were 35%, 9.5% and 14.2% respectively; in addition to this, a further 23.1% was removed with low molecular weight alcohol soluble materials and 12.0% with polar water soluble materials. Thus in water hyacinth, the cell wall acts as an ion exchange column trapping most of the platinum, though some is found bound to water soluble pectates. Together, this accounts for 49.2% of the platinum found in the roots and this figure rises to 68.7% in the leaves. The platinum released by pronase may represent that which is bound to protein from a number of sources including organelle protein, membrane protein and cell wall glycoprotein.

7. Phytoremediation of Lead from Wastewater [20]

Lead is one of the very toxic heavy metals that not only accumulate in individual but also have the ability to affect the entire food chain and disrupt the health system of human beings, animals and phytoplanktons. Hence, proper treatment of lead from soil and industrial wastewaters is very important. Several conventional methods are used for the removal of lead from wastewater includes chemical precipitation, ion exchange and reverse osmosis etc. but major drawbacks with such treatments are produces large amount of sludge and may be ineffective or expensive processes. So, the search for a new, simple, effective and ecofriendly technology involving the removal of toxic heavy metal from wastewater has directed attention towards phytoremediaton. Singh et al revealed at reviewing the potential use of different aquatic plants for remediation of lead contaminated water. Water hyacinth has been listed as most troublesome weed in aquatic system. It is a submerged aquatic plant, found abundantly throughout the year in very large amount and drainage channel system in and around the fields of irrigation. This plant exhibited that Pb accumulated mainly in the roots and the petiole contents comparable at high concentrations than other parts and prolonged immersion. The relatively low leaf contents, until drastic conditions are used, indicated the presence of a prevention mechanism to inhibit Pb uptake. Thus, the water hyacinth would probably have high tolerance and should be capable of removing large amounts of lead from municipal wastewater.

8. Contribution of Water Hyacinth for Removal of Iron from Wastewaters

Iron is considered as one of the essential elements for humans and for other life organisms. On contrary, excess of iron is known to cause hemorrhagic necrosis, sloughing of mucosa areas in the stomach, tissue damage to a variety of organs [21, 22]. Developing countries are yet to enact a permissible limit to the discharging of iron-rich wastewaters into inland surface waters and land despite the fact that high contamination of freshwater resources and groundwater with heavy metals such as iron due to various anthropogenic activities such as blue-print paper, paints and pigments manufacturing facilities, laundry bluing facilities and disposal of sludge from water treatment plants has been a major environmental problem in the industrial areas [21].

Chemical precipitation and phytoremediation are the key mechanisms controlled the removal of iron from wastewaters in batch-type constructed wetlands comprising water hyacinth stands. Moreover, water hyacinth grown under completely nutrient-poor conditions is a promising candidate for a batch removal of excess iron in wastewaters. After a period of approximately 6 weeks, a complete harvesting is recommended to optimize the phytoremediation potential and also to prevent any active effluxing of iron at phytotoxic levels [23].

9. Remediation of Copper by Water Hyacinth in Presence of Microorganisms

Bacteria resistant to copper was isolated from the rhizosphere of water hyacinth and their metal ion removal capacities were determined. Water hyacinths were treated with an antibiotic, oxytetracycline (OTC), to remove most rhizospheric bacteria of plant roots. Inoculation of copper removing rhizospheric bacterium, Strain CU-1, into water hyacinth culture enhanced the copper of the plant roots with or without OTC treatment. Inoculated cells of Strain CU-1 colonized onto the plant roots [24].

10. Accumulation of Metals from Steel Foundry Effluent [25]

Contamination of water and wastewater with heavy metals is emerging as a global environmental challenge. Increasing urbanization, industrialization and over population is leading to the degradation of the environment. The main hazardous contents of water pollution are heavy metals. Water bodies are the main target for disposing of pollutants directly or indirectly. The prevailing purification technologies used to remove the contaminants are too costly and sometimes non-ecofriendly also. Phytoremediation as a low cost and ecofriendly technology for water purification could be most applicable.

Water hyacinth appeared to be more efficient as it minimized all the selected parameters after treatment of 30 days. The changes in initial weight (and also no. of leaves of water hyacinth) of the test plants were also noted in the control and steel industry effluent.

The initial weight of water hyacinth was found to increase in the control and steel industry effluent (Table 3), indicating the test plants was capable of growing in the effluents and could be used for further experimentation.

Table-3. Change in physical parameters (growth) of water hyacinth in control and steel effluent [25]

Physical Parameter	**Water hyacinth**							
	Control				**Steel effluents**			
	Initial	10 days	20 days	30 days	Initial	10 days	20 days	30 days
Initial wt (g)	250	284	320	366	250	294	347	430
Total increase in wt (g)	116				179			
Initial no of leaves	6	9	17	23	6	10	19	25
Total increase in no of leaves	17				19			

Al was accumulated in highest concentration, 16.1634 mg/kg. The shoots of accumulated 14.6647 mg/kg and 1.4987 mg/kg by the roots.

Deposition of As was in the range of 1.3124 mg/kg; 0.6013 mg/kg As was absorbed in the shoots of while the roots 0.7111 mg/kg As.

Water hyacinth deposited Cd in the tissue to the extent of 0.0231 mg/kg. The shoots of the test plants stored 0.0018 mg/kg Cd. In the same way, the plant accumulated 0.0123 mg/kg in the roots. Cr was deposited in at concentrations of 1.7826 mg/kg. 0.7277 mg/kg of the total Cr was deposited in the shoots, while 1.0549 mg/kg remained in the roots.

Total Cu concentrations was 0.1286 mg/kg. Of the total concentration, 0.0851 mg/kg was stored in the shoots, while 0.0435 mg/kg was retained by the roots when harvested from steel effluent. The concentration of Fe was found to be 8.987 mg/kg. The shoots of the test plants showed 7.5503 mg/kg deposition. The roots 1.4368 mg/kg Fe.

The phytoaccumulation capacity of water hyacinth to absorb Mn was 9.6907 mg/kg. The shoots concentrated 6.0546 mg/kg, while 3.6361 mg/kg Mn were deposited in the roots of the test plants.

The concentration of Pb in water hyacinth was 3.2803. The shoots retained 3.0861 mg/kg Pb, whereas the roots gathered 0.7342 mg/kg.

Absorption of Zn from steel effluent and its concentrations in their tissues was 1.5745 mg/kg, while the shoots of the test plants deposited 1.1224 mg/kg. The roots retained 0.4521 mg/kg Zn, when grown in steel effluent.

Aurangzeb et al. found that water hyacinth is a better candidate for phytoremediation for Cd, Cu, As, Al, Pb removal (82.8%, 78.6%, 74%, 73%, and 73%, respectively) and was moderately efficient for Zn, Cr and Fe (65.2%, 62.8% and 61%, respectively), but was a poor remedient of Mn (39.5%). This may be due to its well-developed fibrous root system and large biomass that has been successfully used in wastewater treatment systems to improve water quality by reducing the levels of organic and inorganic nutrients.

11. Phytoremediation of Heavy Metals from Industrial Effluents [26]

Industrial effluents such as the streams of Travancore Titanium Products in India which are producing titanium sponge used for treatment. 10 liters of the effluent was added for treatment of each constructed wetlands. Using fresh water for three times was maintained of each experimental setup and a control. The primary concentration of heavy metals in the plants and aqueous residues have to be analyzed before incorporation into the constructed wetlands. The performance of heavy metals uptake in leaf and root was evaluated relative to bioconcentration factor. The bioconcentration factor is an indicator for accumulation of heavy metals. It could be computed by dividing the concentration of trace element in plant tissues (ppm) by initial concentration of the element in the external nutrient medium (ppm).

$$\text{BCF} = \frac{\begin{array}{c}\text{Concentration of the element}\\ \text{in plant tissues at harvest (ppm)}\end{array}}{\begin{array}{c}\text{Initial concentration of the element}\\ \text{in the external nutrient solution (ppm)}\end{array}}$$

For example, primary concentration of lead was 2.98 ppm. By treatment using different plant based constructed wetlands, negligible decrease in lead concentration is investigated. Water hyacinth based constructed wetlands made the value of lead decrease at a level ($p < 0.05$). It could be noticed that the primary concentration of lead accumulated in leaf was 0.006 mg/g and increased to 0.191 mg/g after treatment process with bioconcentration factor of 64.01. While the initial concentration was 0.008 mg/g then increased to 0.211 mg/g with bioconcentration factor of 70.71 regarding to roots.

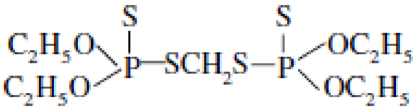
In case of arsenic in effluent, the original amount of 0.016 ppm reduced considerably after treatment using different plant based constructed wetlands. The concentration of 0.001 mg/g increased to 0.012 mg/g in leaf after treatment with bioconcentration factor of 750.0. Bioconcentration factor was 1062.5 in case of root with increase of concentration to 0.017 mg/g after 0.004 mg/g of initial value.

0.096 ppm of copper in the effluent was detected before treatment and 0.005 mg/g in leaf increased to 0.069 mg/g after treatment,. Roots of initial concentration 0.014 mg/g increased to 0.046 mg/g with bioconcentration factor 479.17 was followed.

On the other hand, cadmium was detected of 0.253 ppm in effluent and 0.003 mg/g in leaf increased to 0.015 mg/g with bioconcentration factor 59.29 after the treatment. The initial concentration of cadmium in root was 0.003 mg/g, then increased to 0.024 mg/g with bioconcentration factor of 94.86.

12. Phytoremediation of Phosphorus Pesticide Ethion [27]

Direct uptake and accumulation of contaminants and subsequent metabolism in plant is one of mechanisms suggested for phytoremediation of organic contaminants like phosphorus pesticide ethion. Other mechanisms are according to transpiration of volatile organic hydrocarbons through the leaves or release of exudates that stimulate microbial activity and biochemical transformations around the root system. The forth mechanism that could be processed is enhancement of mineralization at the root–soil interface attributed to mycorrhizal fungi and microbial concortia belonged with the root surface.



$$(C_2H_5O)_2P(=S)\text{—}SCH_2S\text{—}P(=S)(OC_2H_5)_2$$

Chemical structure of phosphorus pesticide ethion

The economic success of phytoremediation largely depends on photosynthetic activity and growth rate of plants. Water hyacinth, due to its fast growth and large biogas production, has potential to cleanup various wastewaters. Organic contaminants such as hydrocarbons, phenols, pesticides and chlorinated solvents can be absorbed. It was recorded that the concentration of ethion in water hyacinth reached its maximum at 72 h in roots and 168 h in shoots (Table 4), implying that some of ethion accumulated in shoots was transported from roots along with the transpiration stream.

This variation could be according to the forthright accumulate of ethion from water by the shoots of water hyacinth. The content of ethion in roots was decreased progressively after 72 h of treatment. This observation supposed that fractions of ethion accumulated in plant tissues could be assimilated by the plant.

The accumulation rate of ethion in water hyacinth was decreased by 74–81% in roots and 55–91% in shoots at the end of one week of incubation in culture media without in absence of ethion. With no detection of ethion residue in the culture medium, the decrease of ethion in water hyacinth might be mainly due to phytodegradation and volatilization. The decrease of ethion in water hyacinth could be mainly resulted from the metabolism. Undetectable morphological changes in water hyacinth for various treatments were established during the experiment. Not only the plant can grow well in polluted water containing up to 1 mgl^{-1} ethion but also it might decontaminate wastewater contaminated with ethion. Accordingly, this plant might provide an efficient, economical and ecological alternative to accelerate the removal and degradation of agro-industrial wastewater polluted with ethion.

Table-4. Concentrations (mean ± SD) of ethion in plant tissues and corresponding culture solutions for the non-sterile planted treatment [27]

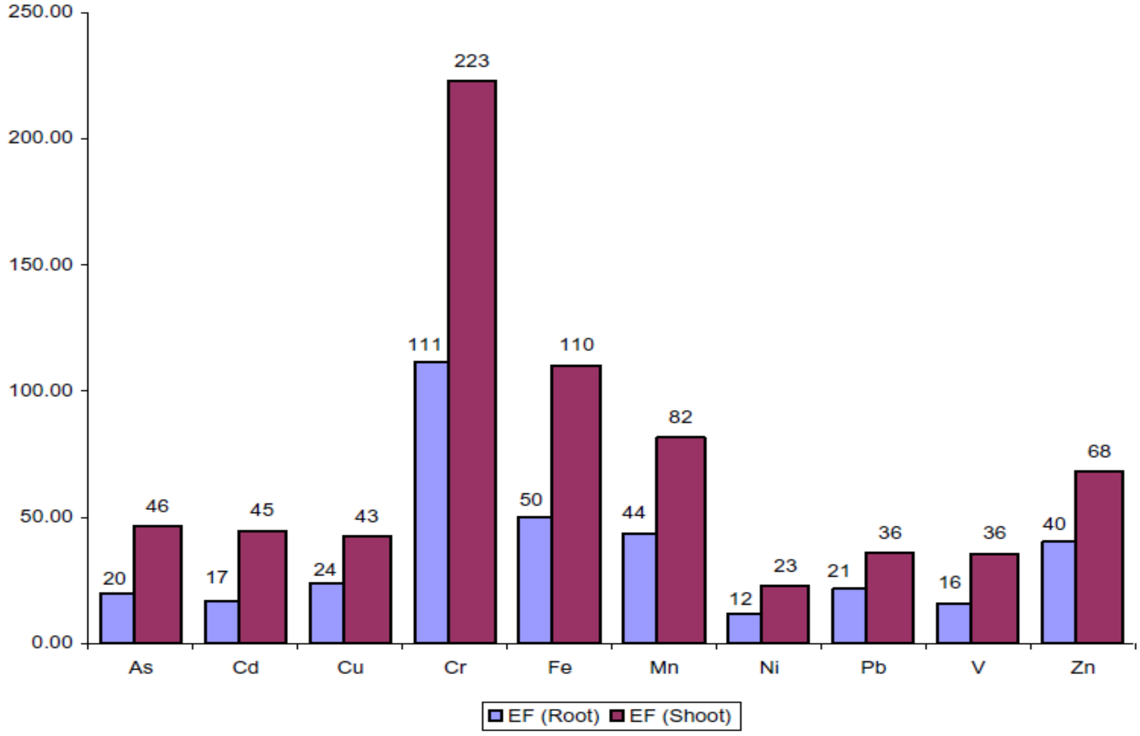
Time (h)	Shoot (μgg^{-1}, DW)	Root (μgg^{-1}, DW)	Culture solution (mgl^{-1})
24	14.4 ± 0.2	188.7 ± 38.9	0.39 ± 0.1
72	21.5 ± 0.1	304.7 ± 57.6	0.30 ± 0.0
120	32.2 ± 19.2	243.0 ± 68.3	0.21 ± 0.1
168	55.7 ± 31.3	219.4 ± 80.8	0.11 ± 0.0
240	39.8 ± 4.5	215.6 ± 81.0	0.06 ± 0.0

13. Enrichment Factors and Translocation of Water Hyacinth [28]

Water hyacinth has been found to accumulate metals in both its 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.

Agunbiade et al., assessed ten metals, As, Cd, Cu, Cr, Fe, Mn, Ni, Pb, V and Zn in water and the plant roots and shoots. The enrichment factors (EF) that measure the degree of metal transfer from the water to the plant roots and shoots for different metals were comparatively reported and the results are presented in Fig. 6. The value of enrichment factor for the shoot is greater than that for the root in each case of the ten metals according to transferring from lower to upper body of the plant. It is worth mentioning that the enrichment factor was high greater than 1 (the value required for phytoremediation plants).

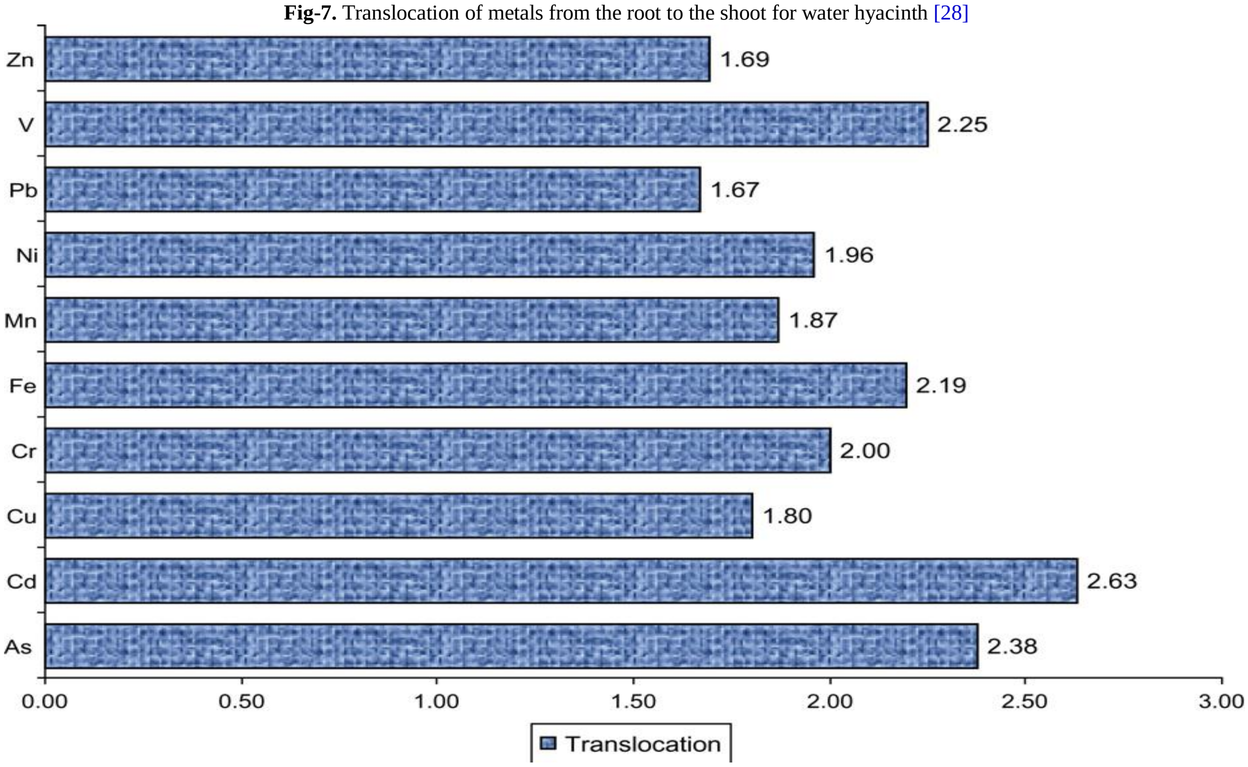
Fig-6. Enrichment factors of the shoot and root for water hyacinth [28]



Least value of enrichment factor was observed at 12 relating to Ni transfer to the root. On the other hand, Cr is the most transferred metal into the root and the shoot then followed by Fe, Mn and Zn respectively. The extremely accumulation of Cr by water hyacinth indicates a potential usefulness of this plant to remediate this metal which is considered with As metal as most problematic pollutants of carcinogenicity classification A (human carcinogen) corresponding to United States Environmental Protection Agency (USEPA). However, cadmium and lead are classified in the same list but with a classification B (probable human carcinogen) [29]. Enrichment factor of As, Cd, Cr and Pb at the root and the shoot reveals the efficiency of water hyacinth as a phytoremedor species. Based on the nature of this plant, shoot and root can be harvested from the water stream as a floating plant resulting in a dense mat covering on the water and consequently implies its ability to purify a wider area of water by quick uptake of the metals.

Translocation of the metals from the root to the shoot is another important feature of phytoremediation which also have to be more than 1 with the plant of an effective ability of phytoremediation. The translocation factor of water hyacinth is presented in Fig. 7.

Fig-7. Translocation of metals from the root to the shoot for water hyacinth [28]



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. According to the high dense, large and sponge leaves of water hyacinth, it is of a higher tendency to include metals within its leaves. Translocation of Cd is arranged the highest followed by As, V, Fe, Cr respectively according to the previous studies stated that Cd displaces Ca and Na through the ion-exchange mechanism [30]. The translocation of other investigated metals was found of a significant value of metals movement from the root to leaf (lower than 2 but higher than 1.5). Phytoremediation technology stated that plants of higher concentration in shoots are classified as phytoextractors due to their genetic potential to absorb metals into the stalk and the leaves. On the other hand, plants that maintain metal absorption or adsorption at the root level were classified as plants used for rhizofiltration process [31]. In this manner, the translocation factor of water hyacinth could nominate it as suitable agent for both phytoremediation technologies; phytoextraction of metals from contaminated water with high ability for rhizofiltration.

14. Phytoremediation Options for Radioactively Contaminated Sites [32, 33]

Artificial radionuclides are also introduced into the environment following nuclear power plant accidents or nuclear weapons tests, nuclear energy activities, scientific and other uses [34-36].

The biological uptake of radionuclides by aquatic organisms and other terrestrial vegetation plays an important role in internal dose delivery [37]. Phytoremediation is an option considered in the radioactive pollution of soils and waters as an easy, environmental-friendly, and energetically inexpensive method in order to clean radioactive-contaminated medium.

Nuclear wastes mainly refer to soil, sediment, sludge, and water contaminated with radionuclides. Rhizosphere biodegradation, phytoextraction, phytodegradation, and phytostabilization are considered as the mechanisms of phytoremediation suggested to radioactive waste management. However, radionuclides are not biodegradable, phytoextraction and phytostabilization are the mechanisms suitable to remediate radionuclides. Phytoextraction including the uptake of radionuclides by the roots from the waste medium and the translocation/accumulation into plant stem and leaves.

Remediation of radionuclides is one of the challenges facing environmental scientists for many decades. Several researchers have explored different types of adsorbents for treating that wastes to get rid of accumulated radiocontaminants [38-40].

Radionuclides transport in soil, sediment, or sludge can be reduced through absorption and accumulation by the plant roots; adsorption onto roots; precipitation, complexation, or metal valence reduction in soil within the root or humification. Subsequently, contaminated plants are harvested from the growing region, dried, and disposed of. Phytostabilization produce chemical compounds of plants and their contents of radionuclides.

Appropriate natural plant species should be selected before applying phytoremediation to remediate the radioactive waste. The suitable plant species used for phytoremediation of radioactive waste should be considered according to the characteristics of radioactive waste, the vegetation plant species, vegetation community composition in the radioactive waste deposited area, the concentration of a remediated radionuclide in and out the plant and the biomass of the plant.

Contamination of soil and water by radionuclides due to natural processes, global fall-out from nuclear weapon testing, discharges from nuclear installations, disposal of nuclear waste and occasional nuclear accidents pose serious problems to biological systems [41, 42]. Thorium in aqueous solutions was remediated by nonliving dried roots of water hyacinth during sorption process [43].

^{60}Co and ^{137}Cs are dominant radionuclides among the fission products and represented as a potential environmental hazard [44]. These two radionuclides release from nuclear accidents and may arise from low-level radioactive waste disposal facilities resulting in a source of radiocontamination for water and soils [45].

Based on the previous studies, water hyacinth was arranged to be efficient in accumulation of radionuclides at all the tested activity contents. With increasing the activity concentration of ^{60}Cs, a slow and steady rate of accumulation was observed during the first day then seems to be stable. On the other hand, ^{60}Co appears to be extremely rapid uptake for all examined activities resulted in more than 90% uptake through the first day and the maximum uptake percent was recorded with the second day of immersion [46].

The initial activity contents is a function of accumulation of radiocesium but not for radiocobalt due to the high radio-toxicity of cesium towards the plants [11]. Accordingly, high content of activities retards metabolic processes and inhibits growth, sometimes is leading to plant death [47]. pH variation seems was an important parameter affecting the competition between metals and metallic ions in the solution [48, 49]. large quantity of protons compete the two radioisotopes (Cs^+ and Co^{2+}) on the adsorption sites of the plant surface at pH 2.9 [50]. Water hyacinth survives and efficiently uptake radionuclides in either acid or alkaline media and has an ability to change the pH of the medium towards neutrality [51].

15. Conclusion

This article presents the different applications of using water hyacinth for the removal of hazardous pollutants present in waste water. Water hyacinth is found to be suitable for controlling the environment against the growing industrial pollution and nuclear applications. According to the innovation use of phtotechnology, it can be a viable tool for the environmental remediation comparing to the traditional processes. It is nearly of no-cost relative to the different advanced technologies which are more expensive to work for the evacuation of pollutants from the contaminated water. Water hyacinth can be recommended as costless, efficient and friendly environmental process for waste water treatment.

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