Bioremediation of Aquatic Environment Using Weeds

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Abstract

Water is a resource that supports life and contamination of water resulting from anthropogenic activities, is a matter of concern worldwide. Water defects and contamination of existing water supplies threaten to be critical environmental issues today for agricultural, domestic and industrial uses. Discharge of municipal sewage and industrial activities deteriorate water quality in urban areas. Synthetic fertilizers, herbicides, insecticides and plant residues released from agricultural activities change the water quality in rural areas. Aquatic plants grow profusely in lakes and waterways all over the world and in recent decades their negative effects have been magnified by man's intensive use of water bodies. Eradication of the weeds has proved almost impossible and even reasonable control is difficult. Turning these weeds to productive use would be desirable if it would partly offset the costs involved in mechanical removal. Among other uses, there has been considerable interest in using aquatic plants for pollution control. Aquatic macrophyteshave been reported to be very efficient in accumulation of heavy metal ions from the water in which they are growing. Bioremedetion is a waste management technique that involves the use of organisms to remove or neutralize pollutants from a contaminated site. Bioremediation exploits the natural capability ofliving organisms to clean environment. It aids in transformation and degradation of contaminants into non-hazardous or less hazardous substances.

Keywords: Aquatic environment, Bioremediation, phytoremediation, weeds

1. Introduction

Water is a resource that supports life and contamination of water resulting from anthropogenic activities is a matter of concern worldwide. Water defects and contamination of existing water supplies threaten to be critical environmental issues today for agricultural, domestic and industrial uses. Metals constitute an important group of environmentally hazardous substances, During this century, many lakes in India have received elevated inputs of heavy metals as a result of an increase in atmospheric activities around the lakes. The eco-friendly means of eliminating these metallic contaminants from the polluted lake water using natural biofilters is very important. (Tiwari et al., 2007). Discharge of municipal sewage and industrial activities deteriorate water quality in urban areas. Synthetic fertilizers, herbicides, insecticides and plant residues released from agricultural activities change the water quality in rural areas. Although nitrates and phosphates content in waste waters act as a nutrient source when used for irrigation but the same becomes pollutant if transported to surface water bodies or leached down to ground water. Besides this, high content of sodium, calcium, magnesium ions in such water contribute to high alkalinity which in addition to nutrients is favorable for enhancing aquatic weed infestation in fresh water bodies

In India, about 73,000 ha of peri-urban agriculture is subject to wastewater irrigation (Strauss and Blumenthal, 1990). In peri-urban areas, farmers usually adopt year round, intensive vegetable production systems (300−400% cropping intensity) or other perishable commodity like fodder and earn up to four times more from a unit land area compared to freshwater irrigation (Minhas and Samra, 2004). The other crops being irrigated with waste water include plantation and horticultural crops as well.

Aquatic plants grow profusely in lakes and waterways all over the world and in recent decades their negative effects have been magnified by man's intensive use of water bodies. Eradication of the weeds has proved almost impossible and even reasonable control is difficult. Turning these weeds to productive use would be desirable if it would partly offset the costs involved in mechanical removal. Among other uses, there has been considerable interest in using aquatic plants for pollution control. Aquatic macrophyteshave been reported to be very efficient in accumulation of heavy metal ions from the water in which they are growing

2. Bioremediation

It is a waste management technique that involves the use of organisms to remove or neutralize pollutants from a contaminated site. According to the EPA, bioremediation is a "treatment that uses naturally occurring organisms to break down hazardous substances into less toxic or non toxic substances". Technologies can be generally classified as *in situ* or *ex situ*. *In situ* bioremediation involves treating the contaminated material at the site, while *ex situ* involves the removal of the contaminated material to be treated elsewhere. Microorganisms used to perform the function of bioremediation are known as "bioremediators".

Bioremediation exploits the natural capability ofliving organisms to clean environment. It aids in transformation and degradation of contaminants into non-hazardous or less hazardous substances.Effective in mitigating hydrocarbons, halogenated organic solvents, halogenated organic compounds, non-chlorinated pesticides and herbicides, nitrogen compounds, metals (lead, mercury, chromium) and radionuclides.

In the era of bioremediation, vegetation or plants as a biological resource with immense capacity for removing variable contaminants from various components of ecosystem have been studied. Plants remove or degrade selected contaminants present in soil, sludge, sediment, groundwater, surface water and wastewater by utilizing their metabolic and hydraulic processes, thereby improving the environment quality that is termed as 'Phytoremediation'.

3. Phytoremediation

It is the treatment of environmental problems (bioremediation) through the use of plants that mitigate the environmental problem without the need to excavate the contaminant material and dispose of it elsewhere.Phytoremediation consists of mitigating pollutant concentrations in contaminated soil, water or air with plants able to contain, degrade, or eliminate metals, pesticides, solvents, explosives, crude oil and its derivatives, and various other contaminants from the media that contain them.

Over the time, green technology became a promising alternativefor treating both organic and inorganic contaminantspresent in water and soil and hence can bean affordable technological solution for wastewatertreatment. The high purification activityof the plants is due to a rapid growth in polluted waste water and capacity to remove contaminants (Miretzky et al., 2004). Bioremediation technologies, including phytoremediation, have been estimated to be 4–1,000 times cheaper, on a per volume basis, than current non-biological technologies. Treatment of organic contaminants mainly involves phytostabilization, rhizodegradation, rhizofiltration, phytodegradation and phytovolatilization mechanisms, while phytostabilization, rhizofiltration, phytoaccumulation and phytovolatilization mechanisms are involved in the treatment of inorganic contaminants.

3.1. Different phytoremediation processes (Vamerali et al., *2010)*

3.1.1. Phytoextraction

It is defined as uptake or absorption and translocationof contaminants by plant roots into the abovegroundportions of the plants (shoots) that can beharvested. Plant species absorb and hyperaccumulatemetal contaminants and/or excess nutrientsin harvestable root and shoot tissue. This processis applicable for metals (Ag, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Zn), metalloids (As, Se), radionuclides (90 Sr, 137 Cs, 234 U, 238 U), non-metals (B, Mg) and organic contaminants present in soils, sediments and sludges (Brooks, 1998).

3.1.2. Phytostabilization

It is defined as the use of plants to immobilize the contaminants in the soil and groundwater through absorption and accumulation in plant tissues, adsorption onto roots or precipitation within the root zone preventing their migration in soil. The plant root exudates stabilize, demobilize and bind the contaminants in the soil matrix, thereby reducing their bio-availability. This processis suitable for organic contaminants and metals present in soils, sediments and sludges. This technique does not require disposal of hazardous materials or biomass and ecosystem restoration is enhanced by the vegetation. Long-term maintenance of the vegetationis the limitation.

3.1.3. Rhizofiltration (Phytofiltration)

It is the removal of contaminants in surface waterby plant roots. It involves adsorption or precipitation onto plant roots or absorption followed by sequestration in the roots. This process is applicable for removal of metals (Pb, Cd, Cu, Fe, Ni, Mn, Zn, Cr), excess nutrients and radionuclide (90Sr, 137 Cs, 238 U, 236 U) present in groundwater, surface water and wastewater (Dushenkov et al., 1995).

3.1.4. Phytovolatilization

It is defined as the plant's ability to absorb, metabolize and subsequently volatilize the contaminant into the atmosphere. Growing treesand other plants take up water along with the contaminants, pass them through the plants leaves and volatilize into the atmosphere at comparatively low concentrations. This processis used for removing metal contaminants present in groundwater, soils, sediments and sludgemedium.

3.1.5. Phytodegradation (Phyto-transformation)

Phytoremediation is a generic term for the group of technologies that use plants for remediating soils, sludges, sediments and water contaminated with organic and inorganic contaminants. It is defined as "the metabolization and degradation of contaminants within the plant or the degradation of contaminants in the soil, sediments, sludges, groundwater or surface water by enzymes produced and released by the plant". Organic compounds such as munitions (trinitrotoluene), chlorinated solvents, herbicides, insecticides and inorganic nutrients are reported to be removed by this technique (Campos et al., 2008).

3.2. Advantages and limitations of phytoremediation
advantages

• The cost of the phytoremediation is lower than that of traditional processes both *in situ* and *ex situ*

• The plants can be easily monitored

• The possibility of the recovery and re-use of valuable metals (by companies specializing in "phyto mining"

• It is potentially the least harmful method because it uses naturally occurring organisms and preserves the environment in a more natural state.

Limitations

• Phytoremediation is limited to the surface area and depth occupied by the roots.

• Slow growth and low biomass require a long-term commitment

• With plant-based systems of remediation, it is not possible to completely prevent the leaching of contaminants into the ground water (without the complete removal of the contaminated ground, which in itself does not resolve the problem of contamination)

• The survival of the plants is affected by the toxicity of the contaminated land and the general condition of the soil.

• Bio-accumulation of contaminants, especially metals, into the plants which then pass into the food chain, from primary level consumers upwards or requires the safe disposal of the affected plant material.

• Aquatic plant species have been explored andstudied extensively for their phytoremediationcapacity. A number of aquatic plant species andtheir associated microorganisms have been usedfor more than a decade in constructed wetlandsfor municipal and industrial wastewater treatment. The aquatic plant biomass represents anabundantly available biological material. The features such as easy cultivation, high biomass production, faster growth rate, surplus availability and high tolerance to survive adverse environmental conditions together with higher bioaccumulation potential establish them aspotential agents for phytotechnology.

3.3. Plant species used in phytoremediation

Aquatic plants also referred to as aquatic macrophytes consist of assemblage of diverse taxonomic groups. They dominatein wetlands, shallow lakes, ponds, marshes, streams and lagoons. They directly influence the hydrology and sediment dynamics of freshwater ecosystems through their effects on water flow.

Macrophytes are broadly classified into three types depending upon their habit of growth:

3.3.1. Free - floating plant species

3.3.1.1. Floating unattached

Plants that fl oat onthe surface of water and roots or submerged leaves hang free in the water, i.e. they arenot anchored to the bottom. Eg : *Lemna*, *Eichhornia*, *Pistia*, *Salvinia*, *Azolla*and *Spirodela*.

3.3.1.2. Floating attached

Plants that have leavesfloating on the surface, stems beneath thesurface and roots anchoring to the substrate.

3.3.1.3. Submerged plant species

They include specieswhere the entire plant is below the surface of the water. Eg: *Potamogeton*, *Ceratophyllum* and *Myriophyllum*

3.3.1.4. Emergent plant species

They include specieswhose stems and leaves are found above the water, while the roots grow underwater.Eg:*Typha*, *Elodea*, *Phragmites*and *Scirpus*.

The ideal plants for phytoremediation should possess the ability to tolerate and accumulate high levels of heavy metals in their harvestable parts, while producing high biomass. Several species of aquatic plants have been used for phytoremediation of wastewater (Khellaf and Zerdaoui ,2009)

4. Hyper Accumulators

Plants that possess the capacity to accumulate high quantities of metals than required for plantgrowth are termed as 'hyperaccumulators'. The concentration noted in these plants are about10–100-fold higher than the levels noted in 'ordinary'non-hyperaccumulator plants (Wani et al. 2012). Eg: *Eichhorneacrassipes* for Cadmium and Zinc (Reeves,2003)

4.1. Potential aquatic macrophytes for phytoremediation

4.1.1. Water hyacinth (eichhornia crassipes)

Water hyacinth is a free-floating perennial aquatic plant wide spread in all tropical climates. *E. crassipes* is known for huge biomass production rate, high tolerance to pollution (Ebel et al., 2007), and absorption capacity of heavy-metal and nutrient qualifyit for use in waste water treatment (Fang et al., 2007).

The chemical investigation of plant parts has shown that it accumulates heavy metals like lead (Pb), chromium (Cr), zinc (Zn), manganese (Mn) and copper (Cu) to a large extent. Of all the heavy metals studied Pb, Zn and Mn tend to show greater affinity towards bioaccumulation. The higher concentration of metal in the aquatic weed signifies the biomagnification that lead to filtration of metallic ions from polluted water.

Alvarado et al. (2008) reported that waterhyacinth removed 600 mg arsenic ha^{-1} day^{-1} under field condition and a removal recovery of 18% under laboratory conditions. Water hyacinth represents a reliable alternative for arsenic bioremediation in aquatic system even though the plant may cause severe water management problems. Water hyacinth has high removal rates for various dye stuffs and heavy metals like iron (Fe), zinc (Zn), copper (Cu), chromium (Cr), cadmium (Cd), manganese (Mn), mercury (Hg) and arsenic (As) from aqueous solutions.

(Priya and Selvan, 2014) So, the use of water hyacinth in phytoremediation technology should be considered carefully.

4.1.2. Common reed (Phragmites australis)

Phragmites australis is a transitional species of two closely attached ecosystems, viz., aquatic and terrestrial, and commonly occurs in marshy wetlands andt is a well-known environmentally resilient species. *Phragmitis australis* is one of the most studied aquatic plants for heavy metal removal (Drzewiecka et al., 2010) because of its high metal removal potential and fast growth, accumulating metal in above and belowground biomass. Plants have a tendency to release excessive metal ions through transpiration, reducing the toxic concentration in the plant tissues of leaves which is common to *P. australis* (Burke et al., 2000). Since, out of 53 heavy metals, only 17 are bio-available, increased transpiration rates increase the bioavailability of metals in *P. australis*. Valuable findings of Southichak et al., (2006) suggest wide tolerance in the reed against most of the toxic metals such as Cu, Ni, Cd, Zn and Pb. However, metal removal and accumulation depend largely on the growing period of plants and their physiological attributes. *P. australis* can withstand higher concentration of Cu (Alia et al., 2002) and is considered as a Cutolerant plant. Higher accumulation of Zn and Mn has been reported in the roots (Peltier et al., 2003). Higher removal of metal ions by *P. australis* with a decreasing trend of accumulation as roots or rhizome of leaf stem (Bonanno, 2011). Most of the metals taken up by the weed remain in rhizomes and roots. Removal of metalloids such as arsenic (As) and antimony (Sb) has also been reported by Ghassemzadeh et al. (2008). Despite having a few environmental demerits such as invasiveness, scientists have proved its ability to restore the quality of environmental matrices. Research reports suggest the proven ability of *P. australis* to remove heavy metal cations from the aquatic environment has enzymatic systems to degrade the xenobiotic organic compounds such as chlorinated pesticides and PCBs. It also helps maintain the oxygen level in water with the help of root-associated *Phragmites spp* microbes.

4.1.3. Duck weed (Lemna minor L.)

Duckweeds are small free-floating aquatic angiosperm plants which do not have distinct stems and leaves. The whole plant body is reduced to form a flat small leaf-like structure called frond. Duckweed family comprises of four genera, Lemna, Spirodela, Wolffia and Wolfiella. Among these four genera, Lemna, Spirodela, and Wolffia have been reported to accumulate arsenic from water (Zhang et al., 2009). Mkandawire and Dudel (2005) studied the bioaccumulation of arsenic in *L. gibba* L. both in field (tailing water) and at laboratory conditions. The mean bioaccumulation coefficients for *L. gibba* were two-folds higher in the laboratory than in the field. In an arsenic removal efficiency study with *L. minor* L., Alvarado et al. (2008) found that the removal rate for *L. minor* was 140 mg arsenic ha^{-1} day^{-1} with a removal recovery of 5% and arsenic accumulation in *L. gibba* L. was correlated negatively with phosphate concentrations. The higher uptake efficiency (2–10 times higher than other duckweed or *Azolla* species) and higher tolerance competence of *Lemnagibba* would place this aquatic plant potential for arsenic phytoremediation (Chaudhary and Sharma, 2014)

Increasing use of arsenic-contaminated underground water for agricultural purposes (irrigation in rice and other crop fields) in the arsenic affected areas, especially in Bangladesh and West Bengal (India), results in the increased concentration of arsenic in fresh water systems posing health threat (Robinson et al., 2006) and remediation of arsenic-contaminated aquatic systems is important for human health. Few aquatic plants (mostly macrophytes) have shown the ability to accumulate high level of arsenic from water. Among those aquatic plants, water hyacinth, duckweed, water fern, Hydrilla and water cresses have been proposed to be potential for phytoremediation due to their arsenic hyper accumulation ability and growth habit. Even though a number of aquatic plants have been shown high arsenic uptake and suggested to be effective for arsenic phytoremediation, the management and disposal of those phytoremediating aquatic macrophytes is a major concern for the successful implementation of phytoremediation technology.

5. Conclusion

Phytoremediation technology is still in its early development stages and full scale applications are still limited. Several aquatic plant species have been proved to be hyper accumulators of metal ions and hence they can be exploited for clean up of the aquatic environment for toxic metal remediations. It is important that public awareness about this technology is considered and clear and precise information is made available to the general public to enhance its acceptability as a global sustainable technology.

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