PHYTOREMEDIATION OF SEWAGE WASTE WATER THROUGH THE APPLICATION OF DIFFERENT FLOATING AQUATIC PLANTS

[1]Mahima Chaurasia, [2]Sanjeev Kumar Srivastava, [3]Arvind Kumar Bajpai, [4]Siddhartha Shukla

[1]Assistant Professor, Institute of Engineering & Technology, Dr. Rammanohar Lohia Avadh University, Ayodhya (U.P.)

[2,3]Assistant Professor, Department of Environmental Sciences, Dr. Rammanohar Lohia Avadh University, Ayodhya (U.P.)

[4]Professor & Head, Department of Environmental Sciences, Dr. Rammanohar Lohia Avadh University, Ayodhya

ABSTRACT

Phytoremediation, a land based aquatic macrophyte sustainable strategy for environmental decontamination, has been gaining much importance. The aquatic plants with their sophisticated metabolic and sequestration detoxification mechanisms have the ability to accumulate heavy metals from soil and water. Constructed wetlands, reed beds and floating plant systems have been common for the treatment of wastewaters for many years. Remediation of soils and sludges, using higher plants, is mostly conceived as an *in-situ* biological technique Heavy-metal pollution is considered a leading source of environmental contamination. Heavy-metal pollution in ground water poses a serious threat to human health and the aquatic ecosystem. Conventional treatment technologies to remove the pollutants from wastewater are usually costly, time-consuming, environmentally destructive, and mostly inefficient. Phytoremediation is a cost effective green emerging technology with long-lasting applicability. The selection of plant species is the most significant aspect for successful phytoremediation. Aquatic plants hold steep efficiency for the removal of organic and inorganic pollutants. Water hyacinth (*Eichhornia crassipes*), water lettuce (*Pistia stratiotes*) and Duck weed (*Lemna minor*) along with some other aquatic plants are prominent metal accumulator plants for the remediation of heavy-metal polluted water. The phytoremediation potential of the aquatic plant can be further enhanced by the application of innovative approaches in phytoremediation. A summarizing review regarding the use of aquatic plants in phytoremediation is gathered in order to present the broad applicability of phytoremediation.

Keywords: Phytoremediation, heavy metal, aquatic plants, floating aquatic plants, wastewater treatment

INTRODUCTION

Water contaminations, along with limited availability of water, have put a severe burden on the environment. Around 40% population of the world is facing the problem of water scarcity due to climate change, rapid urbanization, food requirement and unchecked consumption of natural resources. During the past few decades rapid urbanization, industrialization, agricultural activities, discharge of geothermal waters and olive wastewater especially in olive-cultivating areas enhanced the discharge of polluted wastewater into the environment. Wastewater carrying soaring concentrations of pollutants is immensely noxious for aquatic ecosystem and human health. Reclamation of wastewater has been the only option left to meet the increasing demand of water in growing industrial and agricultural sectors (Tee *et al.*, 2016).

Phytoremediation is a general term for several ways in which plants are used to clean up or remediate sites by removing pollutants from soil and water. Plants can breakdown or degrade organic pollutants or contain and stabilize metal contaminants by acting as filters or traps.

The aquatic plants with their sophisticated metabolic and sequestration detoxification mechanisms have the ability to accumulate heavy metals from soil and water. Constructed wetlands, reed beds and floating plant systems have been common for the treatment of wastewaters for many years (Pandey *et al*., 2001).

Remediation of soils and sludges, using higher plants, is mostly conceived as an *in situ* biological technique (McGrath *et al.*, 1993). The basic tactics that can be followed for phytoremediation of contaminated soils and water include:

a. Phytoextraction that comprises the absorption and accumulation of toxic metals into the harvestable parts of the plants like roots and shoots.
b. Rhizofiltration where plant roots absorb, precipitate and concentrate toxic metals from effluents.

The sewage water is being used in agricultural practice since decades to achieve higher yields. Although, the sewage water and its sludge add valuable nutrients and improve the physical condition of soil, but several studies showed that they leave heavy metals like Cu, Pb, Cd, Cr to the environment (Srivastava & Pandey, 1999; Srivastava *et al.*, 2000; Pandey *et al.*, 2001).

The removal of toxic metals from contaminated industrial or sewage waste through bio reduction by microbes and their subsequent bioaccumulation by plants is considered to be a feasible and cost-effective remediation technology. Aquatic macrophytes play an important role by providing substrates for bacterial growth and by altering the physico-chemical environment in the rhizosphere (Brix, 1993), which is potentially a simple, low cost and self-sustaining option for amelioration of wastewater.

Industrial and domestic untreated wastewater contains pesticides, oils, dyes, phenol, cyanides, toxic organics, phosphorous, suspended solids, and heavy metals. Heavy metals among these toxic substances can easily be accumulated in the surrounding environment. Commercial, activities such as metal processing, mining, geothermal energy plants, automotive, paper, pesticide manufacturing, tanning, dying and plating are held responsible for global contamination of heavy metals. Removal of heavy metals from the wastewater is difficult because they exist in different chemical forms. Most metals are not biodegradable, and they can easily pass through different trophic levels to persistently accumulate in the biota (Gall *et al.*, 2015; Zhu *et al.*, 2016).

Removal of toxic pollutants is extremely important to minize the threat to human health and the surrounding environment. These conventional techniques for the remediation of heavy metals are generally costly and time-consuming. These treatment technologies require high capital investment and in the end, generate the problem of sludge disposal (Grandclement *et al.*, 2017). For the remediation of wastewater polluted with heavy metals contaminants, an environmentally friendly and economical treatment technology is needed (Gonzalez-Gonzalez *et al.*, 2014; Shahid *et al.*, 2018). The current study illustrates an environment-friendly technique phytoremediation for removal of contaminants on a long term basis.

HEAVY METALS IN THE ENVIRONMENT

Anthropogenic and geological activities are the main source of heavy-metal pollution. Activities such as mining, military activities, municipal waste, application of fertilizer, discharge of urban effluent, vehicle exhausts, wastewater, waste incineration, fuel production, and smelting cause the production of metal contaminants. Natural sources of heavy-metal pollution include erosion, weathering of rocks and volcanic eruption. Parent material during weathering is the primary and initial natural source of heavy metals (El-Gammal *et al.*, 2014).

Agricultural pesticides and utilization of fertilizers on agricultural soil have raised the concentration of Cd, Zn, Cu and As in soil. A constantly increasing need for agricultural produce has increased the application of pesticides, fertilizers, and herbicides. This excessive use of these agrochemicals may result in the accumulation of these pollutants in plants and the soil as well. Usage of phosphate fertilizer and inorganic fertilizers to control the diseases of crops, grain and vegetable sometime hold an uneven level of Ni, Pb, Zn, Cd, and Cr. An enormous quantity of fertilizers is applied to deliver the K, P and N in order to improve the growth of crops, which in turn increase the incidence of cadmium, lead, iron and mercury in substantial high concentrations. An input of heavy metal to agricultural land through the excessive use of fertilizers is increasing apprehension about their probable hazard to the environment (Czarnecki & During, 2015)

Wastewater irrigation leads to the buildup of various heavy metals like cadmium, lead, nickel, zinc, etc. Some of these metals like Zn, Cu, Ni, Cd and Pb are frequently present in the subsurface of the soil irrigated with untreated wastewater. Wastewater irrigation for long periods of time increases the concentration of heavy metal in the soil at toxic levels (Islam, *et al.*, 2018). The unregulated dumping of municipal solid waste is also another main source of raised soil contamination load. Open dumps and land filling are the common practices using worldwide to dispose of municipal solid waste. Despite being a useful source of nutrients, these wastes are also a source of some harmful toxic metals as well. Precarious and overload applications of fertilizers, pesticides and fungicides are very important sources of metal pollution. Metal contamination can also be caused by transportation. Maintenance and deicing operations on roads also generate groundwater/surface contaminants. Corrosion, tread wear, and brake abrasion are well-recorded sources of heavy metals generation linked to highway traffic.

PHYTOREMEDIATION

Phytoremediation is considered an effective, aesthetically pleasing, cost effective and environmental friendly technology for the remediation of potentially toxic metals from the environment. Plants in phytoremediation accumulate contaminants through their roots and then translocate this contaminant in the aboveground part of their body. The notion of using metal accumulator plants for the removal of heavy metals and several other contaminants in phytoremediation was first introduced in 1983, but this idea has already been implanted for the last 300 years (Sanchez-Martin *et al.*, 2000).

Use of vegetation, soil and micro biota along with other agrochemical practices makes the vegetative remediation an appealing green technology for the accumulation of different heavy metals (Mahar *et al.*, 2016). The application of in situ and ex-situ remediation is applicable in a phytoremediation process. In situ application is used more commonly because it reduces the multiplication of contaminant in water and airborne waste, which ultimately minimize the risk to the adjacent environment. More than one type of pollutant can be treated on site by the phytoremediation without the need for a disposal site. It also reduces the spread of contamination by preventing soil erosion and leaching (Sova *et al.*, 2009). The cleanup cost of phytoremediation is far less than other conventional techniques of remediation, which is the utmost advantage of this technique. Phytoremediation is a relatively straight forward technique as it does not require any highly specific personnel and exclusive equipment. This is applicable for the remediation of large scale area where other conventional techniques prove to be extremely inefficient and costly as well (Leguizamo *et al.*, 2017).

CHEMICAL ASSISTED PHYTOREMEDIATION

The phytoremediation potential depends upon the phyto-availability of different heavy metals present in the soil. The application of specific chemicals has proved to be a successful technique to boost the bioavailability of heavy metals to plants. Organic fertilizers and chelating reagents are commonly used to decrease the pH of soils, which ultimately enhance the bioavailability and bioaccumulation in plants. In tobacco, decreased pH by application of a chelating reagent showed increased accumulation of Cd. The application of ethylenediaminetetraacetic acid (EDTA) boosted the phytoextraction and bioaccumulation of Cd, Zn, and Pb in various studies (Farid *et al.*, 2013; Hadi *et al.*, 2014). Some other chelating agents, diethylene triamine penta-acetic acid (DTPA) and ethylene glycol tetra-acetic acid (AGTA), also have been proved efficient chelators to enhance the phytoavailability and phytoextraction of heavy metals. Organic acids such as malic acid, acetic acid, citric acid and oxalic acid have been proved effective chelating agents. The phytoremediation potential of plants may also be enhanced by strengthening plants to tolerate heavy-metal stress and toxicity. Application of salicylic acid (SA), has been found effective to alleviate metal stress in the plant, resulting in enhanced phytoremediation potential of plants (Popova *et al.*, 2012; Shaheen *et al.*, 2016).

MICROBIAL ASSISTED PHYTOREMEDIATION

Plant-associated microorganisms have a key role in the remediation of heavy metals from soils. These microorganisms influence the availability and accumulation of heavy metals in soil and plants. Recently, bio-augmentation of plants with particular and adapted microbes has been extensively studied in phytoremediation. Plant growth-promoting rhizobacteria (PGPR) proved to increase biomass production, disease resistance, and reduce metal induced toxicity in bio-augmented plants. Similarly, endophytic bacteria also play a very prominent part in phytoremediation. The plant–endophyte interaction, fortify the plants to tolerate both biotic and abiotic stress (Ashraf *et al.*, 2018). Application of rhizospheric and endophytic bacteria in soils/plants improves plant growth and boosts the phytoremediation potential of plants by enhancing metals availability, metals uptake, accumulation, reduced metal stress in plants. Furthermore, the rhizospheric and endophytic bacteria also enhance the phytoremediation potential of plants by enhancing soil fertility by the production of growth regulators and the provision of essential nutrients. The mycorrhizal fungi in the root zone form an association with the roots of plants, and have a beneficial role in phytoremediation (Coninx *et al.*, 2017). This plant-fungi association enhance the availability of essential plant nutrients through their hyphal network, modify the root exudates, alter soil pH and stimulate the bioavailability of various heavy metals to associated plants.

TRANSGENIC PLANTS

The application of transgenic plants in phytoremediation is a novel approach to enhance the effectiveness of phytoremediation. Specific genes in transgenic plants increase the metabolism, accumulation and uptake of definite pollutants. The ideal plant to engineer for phytoremediation should possess characteristics; high biomass yield adopted to local and target environment and well-established transformation protocol. Transgenic plants also enhance the detoxification process of organic pollutants and the addition of toxic compounds in the food chain (Kozminska *et al.*, 2018; Van Aken, 2008). Firstly, transgenic plants were introduced for the remediation of inorganic pollutants; now they are effectively used to remove organic pollutants from contaminated media. *Nicotiana tabaccum* and *Arabidopsis thaliana* are an example of transgenic plants firstly practiced for effective removal of heavy metals, cadmium, and mercury, respectively. Transgenic plants have been proved efficient for the treatment of phenolic, chlorinated, and explosives contaminants (Eapen *et al.*, 2007; Macek *et al.*, 2008).

AQUATIC PLANTS AND PHYTOREMEDIATION

The aquatic ecosystem is a cost-effective and resourceful clean up technique for phytoremediation of a large contaminated area. Aquatic plants act as a natural absorber for contaminants and heavy metals (Pratas, 2014).

Removal of different heavy metals along with other contaminants through the application of aquatic plants is the most proficient and profitable method. Constructed wetlands along with aquatic plants were extensively applied throughout the world for the treatment of wastewater. The selection of aquatic plant species for the accumulation of heavy metal is a very important matter to enhance the phytoremediation (Galal *et al.*, 2018; Fritioff & Greger, 2003).

Over the years, aquatic plants have gained an overwhelming reputation because of their capacity to clean up contaminated sites throughout the world. Aquatic plants always develop an extensive system of roots which helps them and makes them the best option for the accumulation of contaminants in their roots and shoots. The growth and cultivation of aquatic plants are time-consuming, which may restrict the growing demand of phytoremediation. Nevertheless, this shortcoming is substituted by the number of advantages that this technology possesses for the treatment of wastewater (Kozminska *et al.*, 2018; Syukor *et al.*, 2014).

SIGNIFICANCE OF AQUATIC PLANTS FOR PHYTOREMEDIATION OF WASTEWATER

Phytoremediation of heavy metals with aquatic plants has gained significant consideration due to its elegance and cost-effectiveness. The earlier worker has demonstrated that aquatic plants have the capability to eliminate heavy metals from different kinds of wastewater. Aquatic plants remove heavy metals via absorption or through surface adsorption and integrate them into their system, and then accumulation them in certain bounded forms (Rai *et al.*, 1995; Sas-Nowosielska *et al.*, 2008). Effluents from wastewater mitigated through the aquatic plants, thus causing less harm to the surrounding environment. A wide array of aquatic plants like water hyacinths, *Salvini*a sp., water lettuce, giant duckweed, and *Azolla* sp. has displayed tremendous ability for the phytoremediation of numerous kinds of wastewater (Soda *et al.*,2012; Rodríguez & Brisson, 2015). This review briefly describes the effectiveness of these aquatic plants for the remediation of different types of wastewater.

PHYTOREMEDIATION OF MUNICIPAL WASTEWATER

Municipal wastewater possesses significant risk for the aquatic environment as it is a main cause of heavy metal pollution. Zn, Cu, Ni, Pb and Hg are potentially more noxious metals and they may cause chronic and acute health effects, bioaccumulation and phytotoxicity (Alhadrami *et al.*, 2016). Application of aquatic plants for the removal of heavy metals from municipal wastewater, sewage water, spillage areas, and other polluted sites has become a common practice and experimental technique. Aquatic plants can be used as bio-accumulators as they have the ability to accumulate high concentrations of heavy metals in their biomass. Root and shoot tissues of *Typha domingensis* showed maximum accumulation of Zn, Cd, Ni, Fe and Mn during the first 48 h of study, planted in pots filled with municipal wastewater (Mojiri, 2012). Two rooted macrophytes *Typha angustifolia* and *Phragmites australis* removed 14–85% of heavy metals such as zinc, lead, arsenic, nickel, iron, copper, aluminum and magnesium from municipal wastewater in a hydroponic study (Pedescoll *et al.*, 2015). Similarly, aquatic plants *Typha latifolia* and *Phragmites australis* showed excellent removal efficiency of heavy metals from the municipal wastewater. Both these aquatic plants showed higher removal rate for aluminum (96%), copper (91%), lead (88%) and zinc (85%) and slightly less removal rate for iron (44%), boron (40%) and cobalt (31%) (Morari *et al.*, 2015).

PHYTOREMEDIATION OF INDUSTRIAL WASTEWATER

Discharge of industrial waste into soil and water signifies a more critical threat to human health, living organisms, and other resources (Francova *et al.*, 2017). Phytoremediation, along with newly developed engineering and biological strategies, has facilitated the successful removal of heavy metals from industrial wastewater through both phytostabilization and phytoextraction (Cheraghi *et al.*, 2011).

Southern cattail (*Typha domingensi*) showed maximum accumulation of zinc, aluminum, iron, and lead, especially in roots rather than leaves from the industrial wastewater pond. Rhizofiltration was found as dominant mechanisms, which explained the phytoremediation potential of *Typha domingensis* (Hegazy *et al.*, 2011). *T. domingensis* is such a dominant aquatic plant species having a high tolerance to a toxic environment and proficient in accumulation of heavy metals. Maine *et al*., (2017) also reported that *T. domingensis* showed much better survival and removal efficiency for iron, zinc, nickel, and chromium released from industrial wastewater of metallurgy plant over other higher diversified aquatic plants. Such a type of aquatic plant can be used on a large scale to study the long-term removal performance.

ROLE OF AQUATIC PLANTS IN CONSTRUCTED WETLANDS

Remediation of wastewater through constructed wetland has been magnificently executed over the last few decades worldwide as an appropriate management choice for wastewater (Wang *et al.*, 2017). Constructed wetlands are designed to treat distinct form of wastewater within the controlled environment. A broad range of wastewaters such as agricultural, municipal, landfill leachate, storm water and industrial wastewater (Saeed *et al.*, 2018) can be remediated in constructed wetlands. The constructed wetland provides a comparatively simple and cheap solution for controlling water contamination without disturbing resources of natural wetlands (Rizzo *et al.*, 2020). Aquatic plants are an imperative constituent in constructed wetlands for the remediation of wastewater. Aquatic plants in constructed wetlands have two significant indirect functions: (1) leaves and stem of the aquatic macrophytes enhance the surface area for significant attachment of microbial communities, (2) aquatic plants have the aptitude to transport gases like oxygen down towards the root zone to allow their roots to subsist in the anaerobic environment (Brix, 1997). Rhizospheres excessively support the microbial communities that handle the necessary alteration of metallic ions, different compounds, and nutrients. Therefore, the application of aquatic macrophytes in constructed wetlands helps in the remediation of wastewater polluted with different contaminants and also acts as a sink for the contaminants Leung *et al.*, 2017).

Heavy-metal concentration in wetland aquatic macrophytes generally decreased in the following order: root > leaves > stems. However, the concentration of heavy metals does not deliver sufficient evidence regarding the uptake of heavy metals in aquatic plants in wetlands. In wetlands, uptake of heavy metals depends heavily upon the biomass of the particular aquatic plant (Bhattacharya *et al.*, 2006). *E. crassipes* is one such plant which has the capability to double its biomass within a few days under favorable conditions. Most recently, Rai, 2019 reported the water hyacinth (*E. crassipes*) as the most appropriate wetland plant for the phytoremediation of metals from wastewater. Use of *E. crassipes* in the constructed wetland to remove heavy metals has been recommended as the best choice in order to make use of *E. crassipes* (nuisance weed) effectively throughout the world. Sukumaran *et al.*, 2013 reported the utilization of *E. crassipes* for the phytoremediation of Cd, Pb, Cu, Ar from industrial discharge by applying constructed wetland technology. *E. crassipes* showed much higher remediation potential for Cu, Ni, Fe, Cd, Zn, Cr than the other two free-floating aquatic plants *Pistia Stratiotes*, *Spirodela polyrhiza* during a 15-day experiment.

Dan *et al*., 2017 examined the accumulation of different heavy metals such as Fe, Cd, Zn, Ni, Pb and Cr by *Juncus effuses* and *Phragmites australis* from landfill leachate through a lab-scale constructed wetland. Both aquatic plants showed much higher removal efficacy for the targeted metals. Similarly, Leung *et al*., (2017) also reported high removal percentages for heavy metals with three aquatic plants (*Phragmites australis*, *Cyperus malaccensis* and *Typha latifolia*) in constructed wetlands receiving wastewater from the mining industries. *Typha latifolia* showed maximum removal efficiency of 96%, 95% and 80% for Cd, Cr and Pb correspondingly in a laboratory-scale constructed wetland unit. A constructed wetland with *Phragmites australis* was assessed for the phytoremediation of municipal wastewater. Most of the metals were significantly removed from the municipal wastewater with reasonable efficiencies. Results demonstrated that *Phragmites australis* accumulated most of the heavy metals in their belowground part, and only a minor fraction of metals translocate two aboveground biomass of the plant (Sima *et al.*, 2019).

The study of phytoremediation reveals that the aquatic macrophytes have the advantage over other plants in the remediation of heavy metals. The widespread availability, rapid growth rate, high biomass, cost-effectiveness and tolerance to toxic pollutants make them the best suited, available phytoremediation plants. Purifications systems using these aquatic plants have gained more attention worldwide because of their capacity to accumulate and remove of a persistent organic pollutant from water bodies (Daud *et al.*, 2018).

CONCLUSIONS AND FUTURE PROSPECTS

Heavy metals in our environment as a persistent pollutant need absolute elimination for a completely remedial objective. Utilization of phytoremediation seems to be a less disruptive, economical and environmentally sound clean-up technology. Choice of appropriate plant is the most significant feature in phytoremediation. Aquatic plants perform very vibrant roles in the remediation of heavy metals from the polluted site with equal ease to other hyper accumulator plants. Application of aquatic plants both in bioaccumulation (with living plant biomass) and bio-sorption (with dead plant biomass) can be done successfully for the eradication of heavy metals. Comprehensive interaction, transport, and chelator activities regulate the storage and accumulation of heavy metals by the aquatic macrophytes. Genetic engineering enhances the accumulation and tolerance capacity of plants, which shows its exceptional application in improving the effectiveness of phytoremediation. In plants, at the molecular level, different extensive steps have been evaluated that favor the transgenic methods in order to plead with the changeover metal fraction of plants. Genetically engineered plants show high tolerance and metal uptake capacity and, as a result, gene manipulation has successfully been investigated in terrestrial plants, but, genetic engineering of aquatic plants to enhance their heavy-metal uptake capacity is in its preliminary phases.

Disposal of plant biomass later on, can be used for the production of biogas and also can be used as animal feed. The application of aquatic plants in phytoremediation like other conventional physical and chemical techniques does not require any post-filtration and can be effectively used to treat a large volume of polluted water and soil. Based on the present review, the benefits of using aquatic plants to treat contaminants are huge, because this technology does not only treat the contaminants but is cost-effective and visually pleasing as well as being advantageous for the sustainability of whole ecosystems.

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ABSTRACT

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