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REVIEW ARTICLE

A Review on Bioremediation with Plants for Removal of Heavy Metals in Industrial Waste water

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ABSTRACT

Heavy metal pollution is one of the major problems of environmental pollution. Toxic metals accumulate into the food chain through food crops and lead to various harmful health issues to human health and the ecosystem. The physical methods are more expensive and less effective. As we know the plants have the inbuilt capability to remediate heavy metals therefore, bioremediation with plants gained much attention in the last few years because of its eco-friendly, inexpensive and effective approach. This review aimed to describe the toxic effects of heavy metals on the ecosystem and human health, the mechanism of plants for accumulating and detoxifying heavy metals as well as various hyperaccumulator plants for accumulating heavy metals from wastewater.

Keywords: Industries Wastewater, Heavy Metals, Inexpensive, Remediation, Hyperaccumulator plant.

INTRODUCTION

Environmental pollution is a global problem that is majorly caused by anthropogenic activities such as using fertilizers and pesticides, deforestation, sewage, industrial effluents. The rate of pollution caused by natural disasters is slower than anthropogenic activity. This result in the release of heavy metals which is very hazardous to natural ecosystem as it accumulates into the food chain and can cause severe health issues to humans and other living creature to their habitats. Over the years, conventional methods like physical, chemical, and thermal processes are used for remediation of polluted sites, but they are mostly ineffective as salts of heavy metal get dissolve in water hence unable to be separate, Physico-chemical methods are also available but they are very costly (Hussein *et al.,* 2004). However, Bioremediation is a process in which organic wastes are made less toxic and degraded by using natural biological activity. Bioremediation involves the use of microbes, algae, plants, and enzymes to remove heavy metals (Ojuederie *et al.,* 2017). This process has various advantages over conventional methods such as eco-friendly, low-cost, low-technology, and efficient processes. The residues left after treatment are usually harmless products such as carbon dioxide, water, and cell biomass. The well-known hyperaccumulator plants for bioremediation are Brassicaceae and Arabidopsis thaliana, about 25 % of plants belong to these families (Cobbet, 2000). About 300 years ago, the capability of plants for accumulating heavy metals from wastewater is studied (Hartman, 1975). The use of hyperaccumulator plants is majorly conducted in three continents US, Africa, and Asia. In US Environmental Protection Agency's (EPA), Resource Conservation and Recovery Act (RCRA), the Department of Defense (DOD), Department of Energy (DOE) are the national agencies which take care of treating polluted sites. According to the EPA's Comprehensive Environmental Response Compensation Liability Information System (CERCLIS), there are 30,000 polluted sites that are remediated with plants because of its several advantages (Van der Lelie *et al.,* 2001). In 1995 the "Ecological Engineering and Phytoremediation Research Programme" was initiated by AngloGold Ashanti (then Anglo American Gold Division) and the School of Animal, Plant and Environmental Sciences (APES) of the University of the Witwatersrand, Johannesburg (Wits University) are the popular agencies of south Africa which estimated that there are about 140 plant species which are recently used for bioremediation which later can reach up to 200 species after trial.

In India, overexploitation of natural resources is the major issue that gives rise to various problems in which one of which is heavy metal pollution in water bodies as well as in soil. (Kumar *et al.,* 2008) studied phytoremediation process at Pariyej reservoir, an internationally important wetland listed in the Asian Directory of Wetlands, designated as a "Wetland of International Importance" for various plants with respect to heavy metal accumulation also known as biomonitors. He observed Nelumbo nucifera had the highest accumulation of heavy metal whereas the lowest content in the Echinochloa colonum. (Rai, 2008) studied the fern for phytoremediation called Azolla pinnata in which the studies revealed that Azolla pinnata accumulate Hg (II) ions which inhibit its growth and about 70-94% of metal content decreased in the solution. The proper administration for wastewater discharge of industries is very poor which is very harmful to the ecosystem. The textile industries include various steps such as bleaching, dyeing, printing, and finishing steps which include various chemicals and dyes. Majorly azo dyes are used in decolorization procedures in textile industries which are non-biodegradable and highly toxic in nature and contain heavy metals (Kumar *et al.,* 2014). Some of these dyes are Joyfix Red, Remazol Red, Reactive Red, and Reactive Yellow which is persistent and potentially toxic (Kumar *et al.,* 2015). Heavy metals pollution remains in the environment for several years and can cause "direct" or "indirect damage" to lives. Direct damage is caused by a conformation change in biomolecules and indirect damage is caused by producing free radicals of reactive oxygen and nitrogen species. The effects of heavy metals and their permissible limits are listed in (Table 1).

Heavy Metals Harmful Effect on Water Ecosystem

The persistent pollutants are named heavy metals which are majorly produced from a primarily industrial source, a secondary source is an agricultural field by using pesticides, insecticides, fertilizers, and tertiary sources are natural causes such as volcanic activity, soil erosion, geological weathering, etc. Heavy metals bioaccumulate and enter into the food chain to the food web, which can lead to various serious health problems to marine lives, humans, birds, mammals, etc. Metals such as Arsenic, lead, mercury, copper, cadmium, nickel, zinc, chromium, selenium are toxic at very low levels (Cobbina *et al.,* 2015). The toxicity of heavy metals depends upon two factors. The biotic factors include route of exposure, age, gender, nutritional status of individual, tolerance and abiotic factors include organic substances, pH, temperature, alkalinity and hardness, inorganic ligands, interactions (Tchounwou *et al.,* 2012). High concentrations of heavy metals are found in sewage. The sewage treatment process is applied for the removal of heavy metals which is divided into three stages, the first stage include sedimentation and filtration, the second stage requires biofiltration, aeration, or oxidation ponds for the oxidation process, and the last stage deals with the removal of phosphates and nitrates. Hence, this process is very costly and every industry would not be able to afford so the bioremediation process is advantageous over this process.

Hyperaccumulator Plants for Accumulation of Heavy Metals

The hyperaccumulator plants used in the extraction of heavy metals from water bodies are studied as indicated in (Table 2). The site of heavy metal accumulation differs from one plant to another plant. The maximum accumulation of heavy metal occurs in roots.

Mechanism used by plants for heavy metal accumulation

The common processes used by plants for bioremediation of heavy metals are phytoextraction, phytofiltration, phytostabilization, phytovolatilization, phytodegradation, and Rhizofiltration as listed in (Table 3).The mechanism of uptake of heavy metals basically occurs through roots. There are two types of pathways, the Apoplastic pathway, and the Symplastic pathway. The apoplastic pathway does not require energy whereas the symplastic pathway is the most common pathway which occurs against electrochemical potential gradients and requires energy (peer *et al.,* 2005). In the root cell the channel proteins or H^+-coupled carrier proteins are located in the plasma membrane which is responsible for uptaking and translocating heavy metals.There are basically four families of metal transporter are classified in plants such as ZIP, HMAs, MTPs, and NRAMPs as mentioned in (Table 4).

The plants perform mainly two mechanisms avoidance and tolerance. The avoidance mechanism works at the extracellular level and is called a first-line defense mechanism. Plants either immobilize metal ions, uses a metal exclusion mechanism, release organic acids and amino acids to make ligand for stabilizing metal ions, or change the pH of rhizosphere which causes precipitation of heavy metals to stop reaching metals to other parts of plants (Dalvi and Bhalerao, 2013). However, the tolerance mechanism works intracellular level and it is called a second-line defense mechanism. The heavy metal accumulates in the cytoplasm which detoxifies by making heavy metal ions and ligand chelation which are later on actively transported to the vacuole (Tong *et al.,* 2004) as shown in (figure 1).

CONCLUSION

The industries produce wastewater that is untreated and contains various heavy metals and organic pollutants which emerge concern related health on the environment as well as on terrestrial organisms, aquatic organisms, and humans. The chemical treatment of water is very costly because of which every industry cannot afford. However, bioremediation with plants also called "Green Technology" is a promising approach that is accepted all over the world. However, various limitations are also associated with this method in which one of them is time-consuming. Hence, a single approach is not enough to remediate polluted sites we need a combination of other approaches for valuable results such as the genetic engineering approach, microbes associated approach, enzymes associated approach, etc.

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Table 1: Heavy metal with their impacts along with EPA and Indian standards.

Heavy metals	Impacts	EPA regulatory limit (ppm)	Indian standards mg/l, max
Copper	Liver damage, Wilson disease, insomnia, hepatocellular putrefaction in the liver, headache, and gastrointestinal bleeding.	1.30	3.0
Zinc	Depression, bloody urine, neurological signs and nervous system, continuous vomiting, stomach cramps, abdominal cramps, and pancreatic pain.	0.50	15
Lead	Neurological disorders, skeletal, endocrine, immune systems damage.	15.00	1.0
Cadmium	Kidney damage, liver damage, renal cancer.	5.00	1.0
Nickel	Frank haematuria, renal toxicities, hypothermia, bronchitis, kidney damage, Dermatitis, nausea.	0.20	3.0
Mercury	Damage to kidneys, circulatory system and nervous system, reduced reproductive success, and disrupting endocrine systems.	2.00	0.01
Arsenic	Cardiovascular illnesses, Skin manifestations, visceral cancers.	0.01	0.2
Chromium	Irritation in the stomach and small intestine, respiratory, kidney, liver, headache.	0.10	2.0

Table 2: Heavy metal accumulator Plants.

Name of Plants	Heavy Metal Accumulation	References
Lemna minor L.	Cu, Hg, Zn	(Mo *et al.,* 1989) (Dirilgen *et al.,* 1994)
Hydrocotyle umbellata L.	Cu, Cr, Zn	(Erum *et al.,* 2014)
Myriophyllum spicattum L.	Hg Co ,Cu, Ni, Zn	(Dolar *et al.,* 1997) (Iesagea *et al.,* 2007)
Eichhornia crassipes	Cd, Pb, Zn	(Yadav *et al.,* 2015)
Spirodela polyrhiza	Zn, Pb, Ni	(Sharma And Gaur 1995)
Pistia stratitotes	Hg(II) Fe, Cu	(De *et al.,* 1985) (Galal *et al.,* 2018)
Alfaalfa	Ni(II), Cd(II), Cr, Pb,Zn	(Gardea-Torresdey *et al.,* 1996 and 1998)
Water hyacinth	Zn, Cd, Cr	(Delgado And Inel 1993) (Fett *et al.,* 1994)

Azolla filiculoides	Cu, Cd, Pb	(Fogarty *et al.*, 1999)
Hydrilla verticillita	Cr, Cd Ni, Pb	(Phukan *et al.*, 2015) (Zhang *et al.*, 2020)
Potamogeton natus	Zn, Cu, Cd, Pb	(Fritioff And Greger 2006)
Elodea Canadensis	Ni, Cr	(Kahkonen And Manninen 1998)
Azolla pinnata R.Br	Pb, Zn	(Jain *et al.*, 1990)
panicum virgatum L.	Pb	(Dushenkov 1995)
Carex pendula	Pb	(Yadav *et al.*, 2011)
Ipomoea aquatic	Cd, Hg, Pb	(Gothberg *et al.*, 2002)
Salvinia natans	Zn, Cu, Ni, Cr	(Dhir And Srivastava 2011)
Ceratophyllum demersum	Cu, Fe, Ni, Zn	(Borisova *et al.*, 2014)

Table 3: Processes used by plants for remediating Heavy Metals.

Process	**Function**	**Plants**	**References**
Phytoextraction	Plant removes heavy metals by accumulating them from water or soil.	*Brassica nigra* **L.** *Arabidopsis halleri*	(Bharagava *et al.*, 2008) (Claire-Lise and Nathalie 2012)
Phytostabilization	Plants immobilize heavy metals from the enviroment.	*Osmanthus fragrans, Ligustrum vicaryi L., Cinnamomum camphora, Loropetalum chinense var. rubrum, and Euonymus japonicas.*	(Zeng *et al.*, 2018)
Phytovolatilization	Plants uptake heavy metals and release their volatile contaminants in the atmosphere.	*Arundo donax L.*	(Gaurino *et al.*, 2020)
Rhizofiltration	Plants absorb heavy metals from water mainly with the help of roots.	*Pistia stratiotes* L.	(Galal *et al.*, 2018)
Phytodegradation or phytotransformation	Plant uses metabolic processes to degrade the metals which are taken from the environment.	*Phragmites australis* *Azolla filiculoides*	(He *et al.*, 2017) (Zazouli *et al.*, 2014)

Table 4: Types of Heavy Metal Transporters

Metal transporters	**Function**	**Example**	**References**
ZIP	It uptake and transport heavy metals like Fe, Mn, etc from root to shoot	*Thlaspi caerulescens* and *Arabidopsis halleri*	(Assunção *et al.*, 2001)
HMAs	Transport heavy metals like Zn, Cd, Co, Pb and also perform metal homeostasis	*Oryza sativa*	*(lee et al., 2007)*
MTPs	Translocate heavy metals Zn, Ni to	*Arabidopsis halleri and*	(Gustin *et al.*, 2009)

	intracellular and extracellular compartments.	*Noccaea caerulescen*	
NRAMPs	It is resistant associated macrophage proteins that transport heavy metals such as Cu^{2+}, Mn^{2+}, Co^{2+}, Fe^{2+}, and Cd^{2+}	*Thlaspi goesingense*	(Persans *et al.*, 2001)

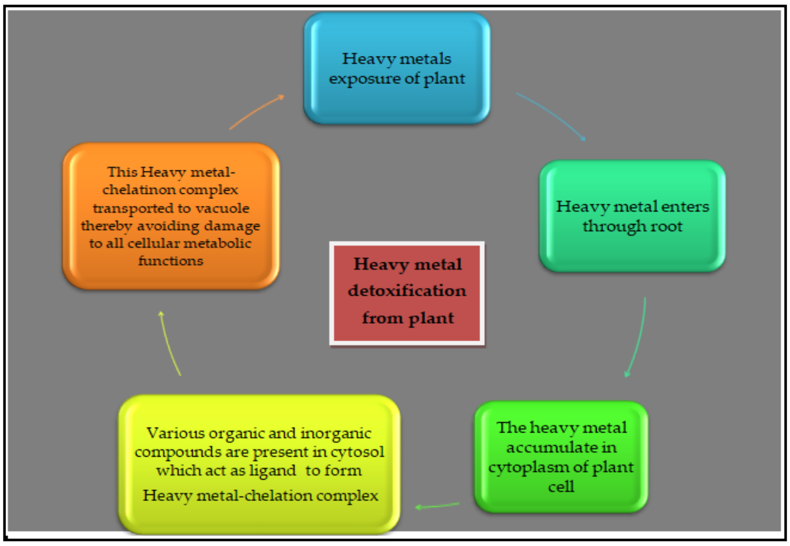

Fig 1: Heavy metal detoxification from plant