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REVIEW ARTICLE

FACTORS AFFECTING PHYTO-ACCUMULATION PROCESS AND HEAVY METALS UPTAKE MECHANISM BY PLANTS - A REVIEW

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ABSTRACT

Heavy metal is one of the serious environmental pollutions for now days as impact of industrial development in several countries. In other hand the heavy metal pollution and plant uptake is one of the most serious issues on now-a-days in industrial areas. Currently plant uptake and phytoaccumulation is one of the serious problems in the world. Due of Phyto-accumulation process and plant uptake heavy metals are accumulated and moved from Root, Stem, Leaf, flower and Fruit, gives toxic effect on human health and cause serious diseases. Several guidelines and recommendations have been suggested to phytoaccumulation process for removing heavy metals / contaminants from the contaminated sites. But these techniques have limitations such as safe high cost-effective disposal mechanisms need to developed and available for contaminated sites / industries.

Keywords: *Contamination; Environmental pollution; Heavy metal; Industrial, Phyto-accumulation, and Plant uptake*

1. INTRODUCTION

Environmental pollution has become a serious public health concern because it becomes a major source of health risk and causes several serious diseases throughout the world [1]. One of the serious environmental pollutions is heavy metals. Although the health effects of heavy metals have been known for a long time, exposure to heavy metals continues and is even increasing in some areas. The effects of heavy metals on human health can even lead to death [2]. The different heavy metal gives different toxic effects on human health as showed by Table 1. Environmental pollution by heavy metals have increased as an influence of industrial development and it was shown that many heavy metals in high level was found in industrial areas [3,4,5]. Heavy metals become a primary concern than other environmental pollutions because heavy metals can't be destroyed by degradation. The remediation process of contaminated soils, groundwater, and surface water by heavy metals needs some methods to remove the metals from contaminated areas [6]. Several methods have been used for removing the pollutants from the contaminated environments. Soils that are contaminated with heavy metals can be treated by acid leaching, soil washing, physical or mechanical separation of the contaminant, electro-chemical treatment, electrokinetic, chemical treatment, thermal or pyrometallurgical separation and biochemical processes [7,8,9,10]. Remediation techniques can be used for removing heavy metals from contaminated ground water are extraction and treatment by activated carbon adsorption, microbes use, air stripping [11], chemical, biological, biochemical and bio-sorptive treatment technologies [9].

Table 1: Toxic Effects of some heavy metals on human health [15].

Sr. No	Heavy Metal	Regulatory Limit (PPM)	Toxic Effects EPA
1	Ag	0.10	Exposure may cause skin and other body tissues to turn gray or blue-gray, breathing problems, lung and throat irritation and stomach pain.
2	As	0.01	Affects essential cellular processes such as oxidative phosphorylation andATP synthesis.
3	Ba	2.00	Cause cardiac arrhythmias, respiratory failure, gastrointestinal.
4	Cd	5.00	dysfunction, muscle twitching and elevated blood pressure Carcinogenic, mutagenic, endocrine disruptor, lung damage and fragile bones, affects calcium regulation in biological systems.
5	Cr	0.10	Hair loss.
6	Cu	1.30	Brain and kidney damage, elevated levels result in liver cirrhosis and chronic anemia, stomach and intestine irritation.
7	Hg	2.00	Autoimmune diseases, depression, drowsiness, fatigue, hair loss, insomnia, loss of memory, restlessness, disturbance of vision, tremors, temper outbursts, brain damage, lung and kidney failure.
8	Ni	0.20	Allergic skin diseases such as itching, cancer of the lungs, nose, sinuses, throat through continuous inhalation, immunotoxin, neurotoxic, genotoxic, affects fertility, hair loss.
9	Pb	15.0	Excess exposure in children causes impaired development, reduced intelligence, short-term memory loss, disabilities in learning and coordination problems, risk of cardiovascular disease.
10	Se	50.0	Dietary exposure of around 300 μg day-1 affects endocrine function, impairment of natural killer cells activity, hepatotoxicity and gastrointestinal disturbances.
11	Zn	0.50	Dizziness and fatigue etc.

EPA: United State Environmental Protection Agency.

2. Source of Heavy Metals in the Environment

Elements with metallic properties and an atomic number >20 is the conventionally definition of heavy metals. Naturally, metals are normal components in soils. However, in high levels, metals can be toxic for plants, animal and microbes [17]. The most common and important heavy metals as contaminant in the environment is As, Sr, Cs, U [12], Cd, Cr, Cu, Hg, Pb and Zn [12,17]. Some of these metals are micronutrients necessary for plant growth and development, such as Zn, Cu, Mn, Ni, and Co, while others have unknown biological function, such as Cd, Pb, and Hg [18].

Heavy metals in the environment come from natural and anthropogenic (human intervention) sources. Minerals weathering, erosion and volcanic activity are the most significant natural sources while for anthropogenic sources are mining, smelting, electroplating, use of pesticides and fertilizer as well as biosolids in agriculture, sludge dumping, industrial discharge, atmospheric deposition, etc.[15,16]. The anthropogenic sources of several heavy metals in the environment presented in table 2.

Table 2: Anthropogenic sources of several heavy metals in the environment [15].

Sr. No	Type of Heavy Metals	Sources
1	As	Pesticides and wood preservatives
2	Cd	Paints and pigments, plastic stabilizers, electroplating of cadmium containing plastics and phosphate fertilizer
3	Cr	Tanneries, steel industries and fly ash
4	Cu	Pesticides, fertilizers
5	Hg	Release from Au-Ag mining and coal combustion and medical waste
6	Ni	Industrial effluents, kitchen appliances, surgical instruments, steel alloys and automobile batteries
7	Pb	Aerial emission from combustion of lead petrol, battery manufacture, herbicides and insecticides

With current intensive agriculture practices and industrialization, pollution of natural resources like land and water with heavy metals, organic pollutants, radionuclides, pesticides, and fertilizers has become a major concern. The phytoaccumulation is one of the serious concerns.

3. Phyto-accumulation:

Phyto means "Plant" and accumulation means "the action or process of accumulating something". It can be defined in biology "the accumulation by a plant of substances from its environment". Phyto-accumulation is otherwise a process, in which plant roots absorb the contaminants along with other nutrients and water. The contaminant mass is not destroyed but ends up in the plant shoots and leaves. This method is used primarily for wastes containing metals. Phyto-accumulation is the uptake of contaminants by plant roots and the accumulation of contaminants into plant shoots and leaves.

Phyto accumulation means roots take up contaminants, typically metals, along with other nutrients and water. The contaminant mass is not destroyed but ends up in the plant shoots and leaves that can be harvested for disposal. It can happens mainly soil contamination. The soil contamination with heavy metals leading to economic losses in agriculture and health problems in humans.

4. Phyto-Accumulation Mechanism:

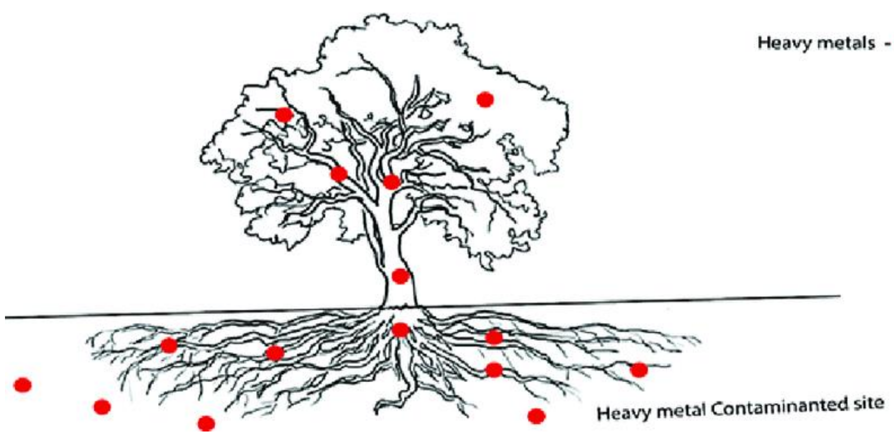

Figure 1: Plants absorb the contaminants and stored them in root, stem, Leaf and Fruit.

In this methodology, plants uptake the metal contaminants and store them in the harvestable regions such as stem, roots and leaves as shown in Fig. 1.

5. Versions of Accumulations:

i) Natural Hyper -Accumulation: Where plants naturally take up the contaminants in soil unassisted.

ii) Induced or assisted hyper-accumulation: Where a conditioning fluid containing a chelator or another agent is added to soil to increase metal solubility or mobilization so that the plants can absorb them more easily. In many cases natural hyper-accumulators are metallophyte plants that can tolerate and incorporate high levels of toxic metals.

6. Process of Phyto-accumulation:

i. Dissolution: The metal needs to be dissolved in something (as an ion in solution), so that, the plant roots can absorb [20].

ii. Root absorption: The plant needs to absorb the metal from the root cell wall to the root [21].

iii. Root-to-Shoot transport: The plants need to chelate the metal in order to both protect itself and make the metal mobile [22].

iv. Storage: The plant moves the chelated metal to a place to safely store it.

v. Adaption: Finally, the plant must adapt to any damages the metals cause during transportation and storage.

7. Mechanisms of Heavy Metal Uptake by Plant:

The Contaminant uptake by plants and its mechanisms have been being explored by several researchers. It could be used to optimize the factors to improve the performance of plant uptake. According to Sinha et al., (2004) [28], the plants act both as "accumulators" and "excluders". Accumulators survive despite concentrating contaminants in their aerial tissues. They biodegrade or bio-transform the contaminants into inert forms in their tissues. The excluders restrict contaminant uptake into their biomass. Plants have evolved highly specific and very efficient mechanisms to obtain essential micronutrients from the environment, even when present at low ppm levels. Plant roots, aided by plant-produced chelating agents and plant-induced pH changes and redox reactions, are able to solubilize and take up micronutrients from very low levels in the soil, even from nearly insoluble precipitates. Plants have also evolved highly specific mechanisms to translocate and store micronutrients. These same mechanisms are also involved in the uptake, translocation, and storage of toxic elements, whose chemical properties simulate those of essential elements. Thus, micronutrient uptake mechanisms are of great interest to phytoremediation [29]. The range of known transport mechanisms or specialized proteins embedded in the plant cell plasma membrane involved in ion uptake and translocation include (1) pro- ton pumps (˝-ATPases that consume energy and generate electrochemical gradients), (2) co- and anti-transporters (proteins that use the electrochemical gradients generated by ˝-ATPases to drive the active uptake of ions), and (3) channels (proteins that facilitate the transport of ions into the cell). Each transport mechanism is likely to take up a range of ions. A basic problem is the interaction of ionic species during uptake of various heavy metal contaminants. After uptake by roots, translocation into shoots is desirable because the harvest of root biomass is generally not feasible. Little is known regarding the forms in which metal ions are transported from the roots to the shoots [29]. Plant uptake-translocation mechanisms are likely to be closely regulated. Plants generally do not accumulate trace elements beyond near-term metabolic needs. And these requirements are small ranging from 10 to 15 ppm of most trace elements suffice for most needs [29]. The exceptions are "hyper accumulator" plants, which can take up toxic metal ions at levels in the thousands of ppm. Another issue is the form in which toxic metal ions are stored in plants, particularly in hyperaccumulating plants, and how these plants avoid metal toxicity. Multiple mechanisms are involved. Storage in the vacuole appears to be a major one [29].

Water, evaporating from plant leaves, serves as a pump to absorb nutrients and other soil substances into plant roots. This process, termed evapotranspiration, is responsible for moving contamination into the plant shoots as well. Since contamination is translocated from roots to the shoots, which are harvested, contamination is removed while leaving the original soil undisturbed. Some plants that are used in phytoextraction strategies are termed "hyper-accumulators." They are plants that achieve a shoot-to-root metal- concentration ratio greater than one. Non-accumulating plants typically have a shoot-to-root ratio considerably less than one. Ideally, hyperaccumulators should thrive in toxic environments, require little maintenance and produce high biomass, although few plants perfectly fulfil these requirements [30].

Metal accumulating plant species can concentrate heavy metals like Cd, Zn, Co, Mn, Ni, and Pb up to 100 or 1000 times those taken up by no accumulator (excluder) plants. In most cases, microorganism's bacteria and fungi, living in the rhizosphere closely associated with plants, may contribute to mobilize metal ions, increasing the bioavailable fraction. Their role in eliminating organic contaminants is even more significant than that in case of inorganic compounds [31, 32].

8. Factors Affecting the Uptake Mechanism

There are several factors, which can affect the uptake mechanism of heavy metals, as shown in Figure 1 by having knowledge about these factors, the uptake performance by plant can be greatly improved.

A) The uptake of compounds is affected by plant species characteristic [34]. The success of the phytoextraction technique depends upon the identification of suitable plant species that hyperaccumulate heavy metals and produce large amounts of biomass using established crop production and management practices [25].

B) Properties of Medium. Agronomical practices are developed to enhance remediation (pH adjustment, addition of chelators, fertilizers) [26]. For example, the amount of lead absorbed by plants is affected by the pH, organic matter, and the phosphorus content of the soil. To reduce lead uptake by plants, the pH of the soil is adjusted with lime to a level of 6.5 to 7.0 [24].

C) The Root Zone. The Root Zone is of special interest in phytoremediation. It can absorb contaminants and store or metabolize it inside the plant tissue. Degradation of contaminants in the soil by plant enzymes exuded from the roots is another phytoremediation mechanism. A morpho- logical adaptation to drought stress is an increase in root diameter and reduced root elongation as a response to less permeability of the dried soil [33].

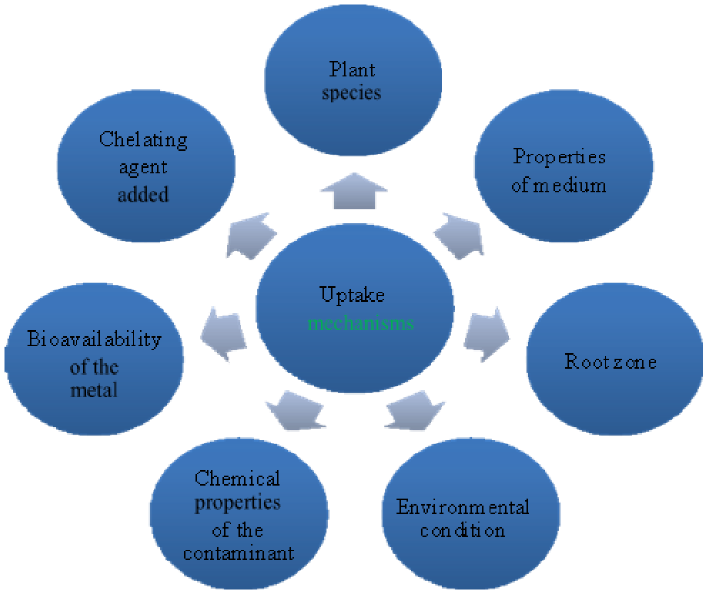

Figure 2: Factors affecting the uptake mechanisms of heavy metals.

D) Vegetative Uptake. Vegetative Uptake is affected by the environmental conditions [44]. The temperature affects growth substances and consequently root length. Root structure under field conditions differs from that under greenhouse condition [33]. The success of phytoremediation, more specifically phytoextraction, depends on a contaminant-specific hyperaccumulator [35]. Understanding mass balance analyses and the metabolic fate of pollutants in plants are the keys to proving the applicability of phytoremediation [36].

E) Metal uptake by plants depends on *the bioavailability* of the metal in the water phase, which in turn depends on the retention time of the metal, as well as the interaction with other elements and substances in the water. Furthermore, when metals have been bound to the soil, the pH, redox potential, and organic matter content will all affect the tendency of the metal to exist in ionic and plant-available form. Plants will affect the soil through their ability to lower the pH and oxygenate the sediment, which affects the availability of the metals [37], increasing the bioavailability of heavy metals by the addition of biodegradable physicochemical factors, such as chelating agents and micronutrients [27].

F) Addition of Chelating Agent. The increase of the uptake of heavy metals by the energy crops can be influenced by increasing the bioavailability of heavy metals through addition of biodegradable physicochemical factors such as chelating agents, and micronutrients, and also by stimulating the heavy-metal-uptake capacity of the microbial community in and around the plant. This faster uptake of heavy metals will result in shorter and, therefore, less expensive remediation periods. However, with the use of synthetic chelating agents, the risk of increased leaching must be taken into account [27]. The use of chelating agents in heavy-metal-contaminated soils could promote leaching of the contaminants into the soil. Since the bioavailability of heavy metals in soils decreases above pH 5.5–6, the use of a chelating agent is warranted, and may be required, in alkaline soils. It was found that exposing plants to EDTA for a longer period (2 weeks) could improve metal translocation in plant tissue as well as the overall phytoextraction performance. The application of a synthetic chelating agent (EDTA) at 5 mmol/kg yielded positive results [38]. Plant roots exude organic acids such as citrate and oxalate, which affect the bioavailability of metals. In chelate-assisted phytoremediation, synthetic chelating agents such as NTA and EDTA are added to enhance the phytoextraction of soil-polluting heavy metals. The presence of a ligand affects the bio uptake of heavy metals through the formation of metal-ligand complexes and changes the potential to leach metals below the root zone [39].

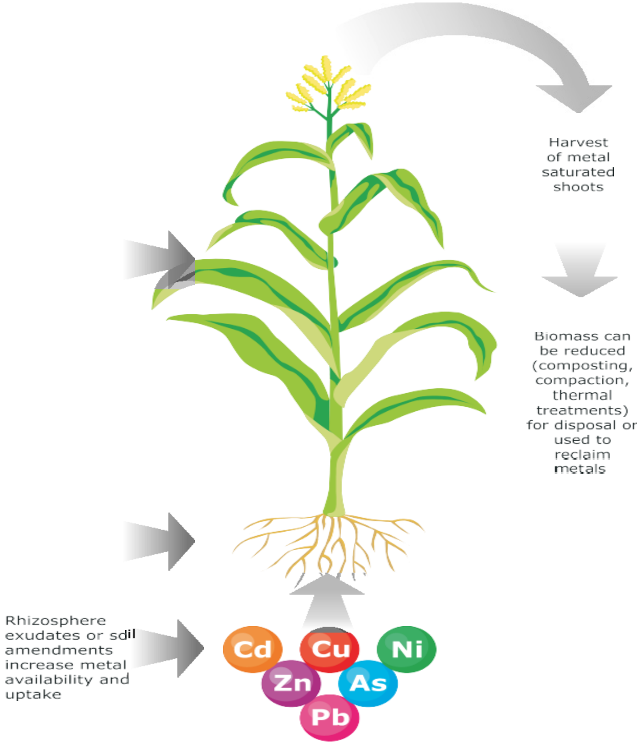

Figure 1: Schematic representation of the processes involved in Phyto-accumulation of Heavy metals / Metals from soils.

8. CONCLUSION

The phytoaccumulation, Heavy metals uptake, by plants methodology, seems to contamination of heavy metals in the environment as well as it effects to human health, loss to farmer for plant growth and yield. There are several factors which can affect the uptake mechanism of heavy metals. Several factors must be eliminated in order to reduce / avoid the phytoaccumulation and plant uptake mechanism which is discussed in the study. The most important factor is a suitable plant species which can be used to uptake the contaminant. The prolong research needs to be conducted in the industrial and contaminated areas in the sites. All the Industries should be followed zero liquid discharge of water and should be submitted their industrial solid waste to authorized agency the treated waste water needs to be used for gardening purpose, encourage research on remediation of ground water, soil and industrial solid waste contaminated sites in industrial areas.

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