A review of phytoremediation technology: heavy metals uptake by plants

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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. Heavy metals give toxic effects on human health and cause several serious diseases. Several techniques have been using for removing heavy metal contaminants from the environmental but these techniques have limitations such as high cost, long time, logistical problems and mechanical complexity. Phytoremediation can be used as an alternative solution for heavy metal remediation process because of its advantages as a cost-effective, efficient, environment- and eco-friendly technology based on the use of metal-accumulating plants. According to previous studies, several plants have a high potential as heavy metals bioaccumulator and can be used for phytoremediation process of heavy metals.

1. Introduction

Environmental pollution has became 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 a 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 being 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, electrokinetics, 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 biosorptive treatment technologies [9].

The use of some of these remediation techniques requires a high cost [10,12,13], a long time [11], logistical problems [14] and technical complexity [15]. Therefore alternative solution is needed for
heavy metals removing from the environment. Bioremediation is an innovative and promising technology available for removal of heavy metals and recovery of the heavy metals in polluted water and lands [16].

Table 1. Toxic effects of some heavy metals on human health [16]

| Heavy Metal | EPA Regulatory Limit (ppm) | Toxic Effects |
|-------------|---------------------------|---------------|
| 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. |
| As          | 0.01                      | Affects essential cellular processes such as oxidative phosphorylation and ATP synthesis |
| Ba          | 2.00                      | Cause cardiac arrhythmias, respiratory failure, gastrointestinal dysfunction, muscle twitching and elevated blood pressure |
| Cd          | 5.00                      | Carcinogenic, mutagenic, endocrine disruptor, lung damage and fragile bones, affects calcium regulation in biological systems |
| Cr          | 0.10                      | Hair loss |
| Cu          | 1.30                      | Brain and kidney damage, elevated levels result in liver cirrhosis and chronic anemia, stomach and intestine irritation |
| 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 |
| Ni          | 0.20                      | Allergic skin diseases such as itching, cancer of the lungs, nose, sinuses, throat through continuous inhalation, immunotoxic, neurotoxic, genotoxic, affects fertility, hair loss |
| Pb          | 15.00                     | Excess exposure in children causes impaired development, reduced intelligence, short-term memory loss, disabilities in learning and coordination problems, risk of cardiovascular disease |
| Se          | 50.00                     | Dietary exposure of around 300 μg day⁻¹ affects endocrine function, impairment of natural killer cells activity, hepatotoxicity and gastrointestinal disturbances |
| Zn          | 0.50                      | Dizziness, fatigue etc. |

*EPA : United State Environmental Protection Agency

Phytoremediation is one of bioremediation techniques can be used as an alternative solution for heavy metal remediation process. The phytoremediation of metals is a cost-effective, efficient, environment- and eco-friendly ‘green’ technology based on the use of metal-accumulating plants to remove toxic metals, including radionuclides as well as organic pollutants from contaminated soils and water [12,15]. The objectives of this review is to give the general information about phytoremediation and use of plants for phytoremediation processes of heavy metals from the environment.

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 are 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 fertilizers
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.

| Heavy Metals | Sources |
|--------------|---------|
| As           | Pesticides and wood preservatives |
| Cd           | Paints and pigments, plastic stabilizers, electroplating of cadmium containing plastics, phosphate fertilizer |
| Cr           | Tanneries, steel industries, fly ash |
| Cu           | Pesticides, fertilizers |
| Hg           | Release from Au-Ag mining and coal combustion, medical waste |
| Ni           | Industrial effluents, kitchen appliances, surgical instruments, steel alloys, automobile batteries |
| Pb           | Aerial emission from combustion of lead petrol, battery manufacture, herbicides and insecticides |

2.1 Phytoremediation and its mechanisms

The term of phytoremediation is relatively new, started from 1991. The term “phytoremediation” consists of the Greek prefix phyto which is means ‘plant’ and the Latin root remedium which is means ‘to correct or remove evil’. Basic information for phytoremediation comes from a variety of research areas including constructed wetlands, oil spills, and agricultural plant accumulation of heavy metals. The term has been used widely since its inception, with a variety of specific meanings [19].

![Phytoremediation mechanisms](image)

Figure 1. Various mechanisms involved in the phytoremediation of heavy metals [16]

Many definitions of phytoremediation have been given by researchers. According to those definitions, [10] have concluded and made the general definition of phytoremediation as an emerging technology using selected plants to clean up the contaminated environment from hazardous contaminant to improve the environment quality. [19] has said that phytoremediation has been receiving attention lately as an innovative, cost-effective alternative to the more established treatment
methods used at hazardous waste sites. [15] have called phytoremediation as ‘green technology’ because of its advantages as a cost-effective, efficient, environment- and eco-friendly technology.

There are numerous plant mechanisms for remediating heavy metal contaminants from the environment. As it functions to remediate contaminant from soils and water, at least there are six mechanisms of plants on phytoremediation process include phytoextraction, phytofiltration, phytostabilization, phytodegradation, phytovolatiation, rhizodegradation [15,16,19]. The summary of the phytoremediation mechanisms is shown in figure 1.

2.2 Plants heavy metals uptake and responses
Several previous studies have described the potential of plant as heavy metals bioaccumulator from contaminated soil and water. The studies have indicated the use of plants through phytoremediation technology is an alternative solution to treat heavy metal contaminated areas and can be used to remediate the environment. Table 3 summarizes the list of several plants reported for heavy metals remediation. Each different plant has also different responses to different heavy metals exposure. Several plants are sensitive while other plants have a high tolerance to several heavy metals. As a consequence of plant-metal interaction, several plants accumulate heavy metals from soil and have growth and development decreases. However, some plants have a high tolerance and can keep the growth and development as well under heavy metals stress.

Different responses of plants to heavy metals exposure depend on its level of heavy metals tolerance. For examples, Chives plants (Allium schoenoprasum) got wilting, yellowing and growth inhibition on Ni, Co and Cd at 0.25 mM concentrations [20]. On chickpea plants (Cicer arietinum), Pb and Cr inhibited the seed germination and decreased the dry weight of plants with increase in metal concentrations and time intervals [21]. Cd stress with 20 μM concentration did not significantly affect root dry weight, shoot height, shoot dry weight, leaf number and total chlorophyll concentration (a and b) of pea plant cv. Kelvedon Wonder except root length compared with the plants grown without Cd treatments [22]. The dry weight of maize plant (Zea mays) extremely decreased on Zn-amended soil with increase in Zn doses. At 270 mg kg⁻¹ dose of Zn, shoot and root dry matter production of maize was 468% and 250% lower than control, approximately. The presence of Zn also changed chlorophyll a fluorescence and antioxidant system parameters [23].

The most important factor affecting the rate of metal removal in phytoremediation is plant selection to be used as accumulator. [17] has described some considerations for the selection of remediating plants:

- The plant biomass, the metal removal rate depends on the plant biomass harvested and metal concentration in harvested biomass.
- Ecosystem protection, native species are preferred to exotic plants, which can be invasive and endanger the harmony of the ecosystem. To avoid propagation of weedy species, crops are in general preferred, although some crops may be too palatable and pose a risk to grazing animals.
- Physical characteristics of soil contamination, for the remediation of surface-contaminated soils, shallowrooted species would be appropriate to use, whereas deep-rooted plants would be the choice for more profound contamination.
Table 3. Several crop plants used to heavy metals phytoremediation studies.

| Plants                         | Contaminated areas | Heavy Metals       | References        |
|-------------------------------|--------------------|--------------------|-------------------|
| *Allium schoenoprasum* L.    | Soil               | Ni, Co, Cd         | [20]              |
| (Chive)                       |                    |                    |                   |
| *Brassica juncea* L.         | Soil and water     | Cd, Cu, Zn, Pb     | [24,25,26,27,28]  |
| (Indian mustard)             |                    |                    |                   |
| *Brassica napus* L. (canola) | Soil               | Cd, Cu, Zn, Pb     | [26,29,30]        |
| *Cajanus Cajan* (L.) Milsp.  | Soil               | As, Cd             | [31]              |
| (pigeon pea)                 |                    |                    |                   |
| *Cicer arietinum* L.         | Soil               | Cd, Pb, Cr, Cu     | [21,32,33]        |
| (chickpea)                   |                    |                    |                   |
| *Cucumis sativus* L.         | Water              | Pb                 | [25]              |
| (cucumber)                   |                    |                    |                   |
| *Eichhornia crassipes* L.    | Water              | As, Cr, Zn, Cs, Co | [34,35,36]        |
| (water hyacinth)             |                    |                    |                   |
| *Jatropha curcas* L.         | Soil               | Fe, Al, Cu, Mn, Cr, As, Zn, Hg | [37,38,39] |
| (purging nut, physic nut)    |                    |                    |                   |
| *Lantana camara* L. (lantana)| Soil               | Pb                 | [40]              |
| *Lens culinaris* Medic. (lentil)| Soil        | Pb                 | [41]              |
| *Lepidium sativum* L. (cress)| Soil               | As, Cd, Fe, Pb, Hg | [42,43]          |
| *Lactuca sativa* L. (lettuce)| Soil               | Cu, Fe, Mn, Zn, Ni, Cd, Pb, Co, As | [42,44,45,46] |
| *Medicago sativa* L. (alfalfa)| Soil            | Cd                 | [47]              |
| *Oryza sativa* L. (rice)     | Soil               | Cu, Cd             | [48]              |
| *Pistia stratiotes* L.       | Water              | Cr, Cd, As         | [49,50,51]        |
| (water lettuce)              |                    |                    |                   |
| *Pisum sativum* L. (pea)     | Soil               | Pb, Cu, Zn, Fe, Cd, Ni, As, Cr | [31,52,53,54,55] |
| *Raphanus sativus* L. (radish)| Soil            | As, Cd, Fe, Pb, Cu | [42,56]          |
| *Spinacia oleracea* L.       | Soil               | Cd, Cu, Fe, Ni, Pb, Zn, Cr | [57,58,59,60,61] |
| (spinach)                    |                    |                    |                   |
| *Solanum nigrum* L. (black   | Soil               | Cd                 | [62,63,64]        |
| nightshade)                  |                    |                    |                   |
| *Sorghum bicolor* L. (sorghum)| Soil            | Cd, Cu, Zn, Fe     | [65]              |
| *Zea mays* L. (corn)         | Soil               | Cd, Pb, Zn, Cu     | [23,61,66]        |

3. Conclusions
Phytoremediation is a remediation technology to clean up the contaminants from environment by using green plants. Phytoremediation can be an alternative solution as a green technology to treat heavy metal contaminated areas. According to previous studies, several plants have a high potential as heavy metals bioaccumulator and can be used for phytoremediation process of heavy metals.

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