Mini Review

Heavy metal toxicity in soils: sources, remediation technologies and challenges

Abstract

Agricultural soils are receiving tremendous amount of pollutants from the various sources. Heavy metal contamination in agricultural soils may impart functional disorders of soils, retarded plant growth and even harm the health of humans through contamination of food chain. These heavy metals or metalloids do not undergo microbial and chemical degradation and persist in the soil for longer duration. This review emphasizes on the sources of heavy metals in soil and remediation technologies involved in their removal from the soil.

Keywords: Anthropogenic sources; Metals / Metalloids; Remediation techniques; Soil pollution

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Introduction

Soil pollution with heavy metals draws a serious concern because of their detrimental effects on the living biota. The persistent and non-biodegradable nature of heavy metals eases their accumulation in the environment. Agricultural soils are receiving tremendous amount of pollutants from the various sources. During the last few decades, rapid urbanization, industrialization, injudicious and faulty agricultural practices influence the release of metal contaminants in the agricultural fields. Heavy metal contamination in agricultural soils may impart functional disorders of soils, retarded plant growth and even harm the health of humans through contamination of food chain. The heavy metals bioaccumulate in the living systems and their concentrations increase as they pass from organism of lower trophic level to higher trophic level, a phenomenon known as biological concentration. According to Babula et al.,[1] heavy metals are the ill-defined subset of elements having a higher molecular weight that includes transition metals, some metalloids, lanthanides and actinides with specific density greater than water, *i.e.,* 5g cm-3. They are classified as essential and non-essential on the basis of their function in living organisms. Essential heavy metals like Zinc (Zn), Nickel (Ni), Manganese (Mn) and Iron (Fe) etc are required by the plants for performing various physiological and biochemical functions. Non-essential heavy metals like Lead (Pb), Aresenic (As), Cadmium (Cd), Chromium (Cr) and Mercury (Hg) etc have no physiological role and they entered the living systems through food chain. Beyond critical limits, heavy metals impart hazardous impact on human health as they hinder the normal functioning of the living systems. ATSDR[2] has listed arsenic, lead, mercury and cadmium at first, second, third and seventh position in terms of their frequency, toxicity and potency for human exposure. The increasing production of livestock and poultry products has led to generation of large amount of wastes into the soil from the industries. The large quantity of waste produced must be treated properly keeping into consideration the environmental measures involved in land treatment. The elevated heavy metal levels in the agricultural soils depend on the characteristics of the soil and the rate of application by the supplier with its elemental concentration. These heavy metals or metalloids do not undergo microbial and chemical degradation and persist in the soil for longer duration. Due to the increasing awareness among the public and the detrimental effects of these contaminants on human health, scientific communities are focusing on development of some new technologies for removal of these metals from contaminated soils. This review focuses on sources of heavy metals in soil, strategies or the technologies involved in their removal from the contaminated soils and further the challenges involved in use of various amendments for remediation of soils.

Sources of heavy metals in soil

Both natural and anthropogenic inputs are correlated with the distribution of heavy metals in the soils. Natural sources include geological breakdown of parent rock materials, volcanic eruptions etc. Anthropogenic inputs like extensive use of agrochemicals (inorganic and organic) fertilizers, pesticides, waste water irrigation, sewage sludge supplementation, higher atmospheric depositions by industrial units and combustion of fossil fuels have led to elevated level of inorganic pollutants in the soils,[3] Fungicides, phosphate fertilizers and inorganic fertilizers have variable levels of Pb, Cd, Cr, Ni, Zn etc depending upon their sources. The repeated use of phosphate fertilizers continuously making the agricultural soils enriched with heavy metals. Both natural and anthropogenic sources of heavy metals in the environment are illustrated in Figure 1.

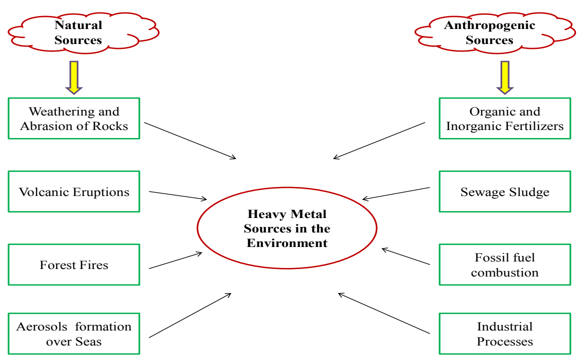

Figure 1: Sources of heavy metals in the environment.

Remediation technologies involved in removal of heavy metals from soil

Several measures have been devised for remediation of heavy metals from contaminated sites. USEPA[4] classified remediation measures of contaminated soils into two types: *in-situ* and *ex-situ* treatment. In *in-situ* treatment, soil is treated at its original place, whereas in *ex-situ* the contaminated soil is moved, excavated and removed from the site. Further, the remediation technologies can be divided as physical remediation, chemical remediation and biological remediation.

Physical remediation

The physical remediation of soils mainly includes replacement of soil and thermal desorption of soil. In soil replacement method, the contaminated soil is partly replaced by clean soil so as to minimize the concentration of contaminant in the soil.[5] However, this method is costly and is feasible only in a small area. On the contrary, in the thermal desorption method, the contaminated soil is heated so as to volatilize the pollutant in the soil. These volatile metals are collected using vacuum pressure and are thus removed from the soil.[5] However, being laborious and costly, this method finds limited applicability in remediation of soils.

Chemical remediation

Chemical remediation involves chemical leaching, chemical fixation, electrokinetic remediation and vitrification etc. The chemical leaching process involves the washing of contaminated soils with water, reagents, fluids and gases that helps the pollutant to leach out from the soil. The metals extracted by this method are recovered from the leachate by using chelating agents, surfactant etc.[6] In chemical fixation, some reagents are added to the contaminated soils that form insoluble bond with the heavy metals and decrease their mobility in the soils.[7] The soil contaminated by heavy metals can be remediated by the process of electrokinetic remediation, which involves the application of high voltage to the soil for the removal of metal.[8] Lastly, the process of vitrification involves heating of the soil at very high temperature (1400-2000°C) so that the pollutant gets volatilize or decompose. However, being costly, laborious and complicated process, its application in removal of contaminants from soil is limited.

Biological remediation

It includes phytoremediation and microbial remediation for removal of heavy metals from the soils. Phytoremediation involves any of the five strategies: phytoextraction, phytostabilization, rhizofilteration, phytovolatalization and phytodegradation.[9] Phytoextraction involves the transfer of metals from the soil to the above ground plant parts, thereby resulting in a decrease in metal concentration in the contaminated soils. On the other hand, phytostabilization refers to the use of plants to reduce mobility and bioavailability of the metals in the soil. Rhizofilteration involves the use of plant roots to remove toxic materials from the contaminated water. Phytovolatalization involves the absorption of contaminants from the soil by the plants, their upward movement and then release from the aerial parts. Phytodegradation, however, involves the use of plant roots and associated microbes to degrade the pollutants present in the soil.[10] Of these strategies, phytoextraction and phytovolatalization are the main options for the removal of heavy metals, whereas phytostabilization and phytodegradation are largely used for organic contaminants.[11] Another method of biological remediation is the use of microbes for removal of heavy metals. The microorganisms change the physical and chemical properties of the pollutants and thus affect the mobility and transformation of heavy metals in the soils.

Challenges related to remediation technologies

The remediation technologies described above are costly, time-consuming and laborious, so efforts are made to increase the solubility of these metals in the soil so that they can be freely available for the removal. The use of chelating agents and surfactants in remediation technologies to increase the removal of pollutants from the soil pose serious problems like leaching of contaminants to groundwater and remobilization of metals in the soils due to their highly stable nature.

Conclusion

The toxicity of heavy metals in the soil is one of the serious problems in the world. The various *in-situ* and *ex-situ* technologies available for contaminated soils are employed to reduce, remove and degrade the heavy metals from the soil. However, the chelating agents or surfactants used in these technologies can get leached to the groundwater, thereby harming the water table. Moreover, the amendments used for immobilizing the contaminants may not be specific for a particular metal and thus can lead to release of a toxic metal into the soil. Thus more studies are needed in future to develop new methods that can effectively lead to removal of heavy metals from the contaminated soil.

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Conflict of interest

The author declares no conflict of interest.

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