A review on heavy metal pollution, toxicity in agricultural soil and remedial measures

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ABSTRACT

Soil heavy metals (some metals and metalloids possessing biological toxicity, such as lead, chromium, arsenic, zinc, cadmium, copper, mercury and nickel) pollution has become a worldwide environmental issue that has attracted significant public attention, mainly from the rising concern for the security of agricultural products. Soils are receiving terrific amount of pollutants from the various sources and these heavy metal contamination in agricultural soil may impart functional disorders of soils, retarded plant growth and even harm the health of soil organisms and humans through contamination of food chain. These heavy metals or metalloids do not undergo chemical and biological degradation and remaining in the soil for longer duration and enter the agro- ecosystem through natural process and anthropogenic activities. Among the remediation using physical, chemical and biological methods, Phytoremediation has proven to be a promising demonstrated available technology to conventional approaches to solve the problem due to its cost effectiveness, aesthetically pleasing and environmental friendly nature. However further comprehensive multidisciplinary researches integrating with biotechnological approaches are needed to improve plant tolerance and minimizing the accumulation of toxic metals in soils. Remediation of heavy metal contaminated soils is necessary to reduce the associated risks, make the land resources available for agricultural production, scale down land tenure problems and enhance food security. This review emphasizes on the sources of heavy metals in soil and remediation technologies involved in their removal from the soil.

Keyword: - *heavy metals[1], environmental issue[2], pollutants[3], contamination[4], Phytoremediation[5], Remediation[6], soil[7], food security[8]*

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1. INTRODUCTION

Soil pollution due to heavy metals draws a severe concern because of their unfavorable effects on the living biota. The persistent and non-biodegradable nature of heavy metals eases their accumulation in the environment and soils are receiving tremendous amount of pollutants. With the development of the global economy, both type and content of heavy metals in the soil caused by rapidly expanding industrial areas, rapid urbanization, disposal of high metal wastes, mine tailings, leaded gasoline and paints, faulty agricultural practices, sewage sludge, waste water, coal combustion residues, spillage of petrochemicals, and atmospheric depositions have steadily increased, resulting in the decline of the environment. Heavy metal contamination in agricultural soils may impart functional disorders of soils, retarded plant growth and harm the health of organisms through contamination of food chain (soil-plant-animal-human), reduction in food quality, reduction in land usability for agricultural production causing food insecurity, contaminated ground water and land tenure problems by bioaccumulation in the living systems and their concentrations increase as they pass from lower tropic level to higher tropic level organisms, this phenomenon called as biological concentration. Heavy metals are a number of an ill-defined subset of elements that exhibit metallic properties and those most commonly found at polluted sites includes the transition metals, some metalloids, actinides and lanthanides, are arsenic (As), lead (Pb), chromium (Cr), cadmium (Cd), copper (Cu), zinc (Zn), nickel

(Ni) and mercury (Hg). According to ATSDR list, arsenic, lead, mercury and cadmium at 1st, 2nd, 3rd and 7th position in terms of their frequency, toxicity and potency for human exposure. Soils are the major sinks for heavy metals released into the environment by anthropogenic activities and do not undergo microbial or chemical degradation. Changes in their bioavailability and chemical forms are possible. The large quantity of waste produced must be treated appropriately keeping into consideration the environmental measures involved in land treatment. The levels of heavy metals in the agricultural soils depend on the soil characteristics and the rate of concentration of contaminated heavy metals. Because of the increasing awareness among the public and the detrimental effects of contaminants on health, scientific communities are focusing on development of some innovative technologies for removal of those metals from the contaminated soils. Soil washing, Immobilization and phytoremediation techniques are the best demonstrated available technologies for effective remediation of heavy metal contaminated sites. In spite of their cost-effectiveness and environment friendliness, field applications of those technologies have only been practiced in developed countries. In most developing countries, these are yet to become commercially available technologies possibly because of the inadequate awareness of their principles of operation and inherent advantages. In developing countries with huge population density and low funds available for environment restoration like India, ecologically sustainable and low cost remedial options are required to restore polluted agricultural lands so as to minimize the risks and problems, enhance food security and overall make the land resource available for agricultural production.

This review focuses on types and sources of heavy metals in soil, strategies involved in their removal from the contaminated soils and further the challenges involved in use of various methods.

2. HEAVY METALS/METALLOIDS

Any metal or metalloid species may be considered a contaminant and occurs where it is unwanted or in a form or concentration that causes a detrimental human or environmental effect. These include cadmium (Cd), lead (Pb), chromium (Cr), mercury (Hg), copper (Cu), arsenic (As), nickel (Ni), silver (Ag), selenium (Se) and zinc (Zn). Other less common metallic contaminants include aluminium (Al), cobalt (Co), cesium (Cs), molybdenum (Mo), manganese (Mn), uranium (U) and strontium (Sr).

3. SOURCES OF HEAVY METALS IN SOIL

Both anthropogenic and natural inputs are correlated with the distribution of heavy metals in the soils.

- **Natural sources-** volcanic eruptions, geological breakdown of parent rock materials etc.
- **Anthropogenic sources-** excessive and improper use of pesticides, fertilizers and other organic and inorganic agro-chemicals, sewage sludge supplementation, waste water irrigation, combustion of fossil fuels and higher atmospheric depositions by industrial units have led to elevated level of inorganic pollutants in the soils. Those have variable levels of Cd, Pb, Cr, Ni, Zn etc. depending upon their sources and continuously use of them, soils are becoming enriched with heavy metals.

Heavy metals in the soil from anthropogenic sources tend to be more mobile, that's why bio available than pedogenic or lithogenic sources. Metal bearing solids at contaminated sites can originate from a wider variety of anthropogenic sources in the form of disposal of high metal wastes in improperly protected landfills, metal mine tailings, lead based paints, leaded gasoline, manures, pesticides, composts, coal combustion residues, fertilizers, petrochemicals, atmospheric depositions and biosolids are discussed under.

3.1 FERTILIZERS

Excess and improper quantities of fertilizers are repeatedly added to the agriculture land in farming systems to provide N, P, and K for better crop growth and development. These elements contain trace amounts of heavy metals as impurities such as Cd and Pb including F, Hg and Pb.

3.2 WASTEWATER

Long term irrigation of crop fields with wastewater, result various heavy metal accumulations in the soil.

3.3 PESTICIDES

Most of using pesticides contain Hg, Cu, Pb, Mn and Zn. Examples of such pesticides are copper containing fungicidal sprays such as copper oxychloride and copper sulphate. For controlling some parasitic insects lead arsenate was used for many years. These elements have the potential to cause problems, particularly if sites are re-developed for other agricultural purposes.

3.4 BIOSOLIDS AND MANURES

Biosolids such as composts, livestock manures, sewage and sludge, add heavy metals (Cd, As, Cr, Cu, Pb, Ni, Mo, Zn Se, Sb, Tl, Hg etc.) in the soil. Cu and Zn may also the potential to cause metal contamination of the soil. These metals added to land in applications of biosolids, can be leached downwards through the soil profile and contaminate groundwater.

3.5 AIR-BORNE SOURCES

Airborne sources of metals include duct emissions of gas, air or vapor steams, and fugitive emissions such as dust from waste piles or storage areas. Major source of soil contamination is the aerial emission of Pb from the combustion of petrol containing tetraethyl lead. Pb, Cd and Zn has been found in very high concentration in plants and soils adjacent to smelting works and roads, the sources being lubricant oils and rubber industries.

3.6 INDUSTRIAL WASTES

Directly discharged Pb, Zn etc. particles during mining and tailings have resulted in contamination of soil that poses human as well as ecological health risk.

4. CHARACTERISTICS OF HEAVY METAL CONTAMINATION OF SOILS

- **Strong latency-** Heavy metal contamination is odorless and colourless, so it is difficult to be noticed. When it exceeds the environmental tolerance or environmental conditions have changed, heavy metal in the soil may be activated and cause serious damage.

- **Wide distribution-** Almost a serious threat to every country and has become increasingly common.

- **Complex contamination-** In recent years more cases are found to be caused by a variety of heavy metals. The complex contamination caused by a variety of heavy metals will always amplify the contamination by heavy metals individually.

- **Remediation problem and Irreversibility-** It is difficult to use dilution techniques to eliminate heavy metal contamination and needs relatively high cost and cycle is also so long.

5. LIVING ORGANISMS AND HEAVY METALS

Living organisms require varying amounts of heavy metals such as cobalt, copper, iron, manganese, zinc and molybdenum. Excessive levels can be damaging to the organism because of their toxicity at high amount and their accumulation over time in the bodies of animals can cause serious illness and thereby disrupt function in vital organs and glands.

List- 1: Types of heavy metals and their effect on human health with their permissible limits.

Pollutants	Major sources	Effect on human health	Permissible leve (mg/l)
Arsenic	Pesticides, fungicides, metal smelters	Bronchitis, dermatitis, poisoning	0.02
Cadmium	Welding, electroplating, pesticide fertilizer, Cd and Ni batteries, nuclear fission plant	Renal dysfunction, Lung disease, Lung cancer, Bone defects (Osteomalacia, Osteoporosis), increased blood pressure , kidney damage, bronchitis, gastrointestinal disorder, bone marrow, cancer	0.06
Lead	Paint, pesticide, smoking, automobile emission, mining, burning of coal	Mental retardation in children, developmental delay, fatal infant encephalopathy, congenital paralysis, sensor neural deafness and, acute or chronic damage to the nervous system, epilepticus, liver, kidney, gastrointestinal damage	0.1
Manganese	Welding, fuel addition, ferromanganese production	Inhalation or contact causes damage to central nervous system	0.26
Mercury	Pesticides, batteries, paper industry	Tremors, gingivitis, minor psychological changes, acrodynia characterized by pink hands and feet, spontaneous abortion, damage to nervous system, protoplasm Poisoning	0.01
Zinc	Refineries, brass manufacture, metal Plating, plumbing	Zinc fumes have corrosive effect on skin, cause damage to nervous membrane	15
Chromium	Mines, mineral sources	Damage to the nervous system, fatigue, irritability	0.05
Copper	Mining, pesticide production, chemical industry, metal piping	Anemia, liver and kidney damage, stomach and intestinal irritation	0.1

Plants experience oxidative stress upon exposure to heavy metals that leads to cellular damage and disturbance of cellular ionic homeostasis. Plants have evolved detoxification mechanisms mainly based on chelation and subcellular compartmentalization to minimize the detrimental effects of heavy metal accumulation and their exposure.

6. HEAVY METALS AND VEGETABLES

Intake of heavy metal polluted vegetables may pose a risk to the human health and is one of the most significant aspects of food quality assurance because of no-biodegradable and persistent nature of contaminants, which may be deposited on the surfaces and then absorbed into the tissues of vegetables.

7. REMEDIATION OF HEAVY METAL

7.1 ENGINEERING REMEDIATION

Engineering remediation consists of using chemical and physical methods to control heavy metal contamination of soils.

7.1.1 REPLACEMENT OR ISOLATION OF CONTAMINATED SOIL

Replacement of contaminated soil means adding large amount of fresh and clean soil for covering the surface of the contaminated soil and blending, means remove the contaminated soil and renew it with the clean soil which is needed for the critically contaminated soil with small area but to completely remedy it still needs other auxiliary engineering measures. However, these methods will cost large amount of material resources and manpower, and can only be applied to small area of soils.

7.1.2 THERMAL DESORPTION METHOD

The contaminated soil is heated so as to volatilize the contaminant in the soil. By the help of vacuum pressure, these volatile metals are collected. Being costly and laborious, this method finds limited applicability in remediation of soils.

7.1.3 ADSORPTION

Adsorption method is based on the fact that almost all heavy mtal ions can be fixed and adsorbed by clay mineral, slag, etc.

7.1.4 SOIL LEACHING

The principle of soil leaching is to wash the heavy metal contaminated soil with specific reagents and thus remove the heavy metal complex and soluble irons adsorbed on the solid phase particles. After separation, heavy metals are then recycled from extracting solution.

7.1.5 OTHER METHODS

Other engineering methods include physical solidification, chemical improvers, chemical curing lamp remediation, washing and compounding etc.

7.2 BIOREMEDIATION

It includes microbial remediation and phytoremediation for removal of heavy metals from the soils. Phytoremediation involves any of five strategies- phytoextraction, phytostabilization, rhizofilteration, phytovolatalization and phytodegradation. This is new technique of remediation by growing specific plants in the soil contaminated by heavy metals. These plants have the certain hyper-accumulation ability for the contaminants in the soil. Heavy metals accumulate mainly in the roots or above the roots of these plants. When the plants are reach certain enrichment level of heavy metals, remove heavy metals in the contaminated soil layer thoroughly by burning, harvesting and curing these plants, thereby resulting in a decrease in metal concentration in the contaminated soils. Now a day’s more than 400 species of such plants have been found in the world, and most of them belong to Cruciferae family, including the genus Alyssums, Brassica and Thlaspi etc. (Xing et al., 2003).

7.2.1 PHYTOSTABILIZATION- Use of plants to reduce bioavailability and mobility of the metals in the soil

7.2.2 RHIZOFILTERATION- Use of plant roots to remove toxic materials from the contaminated water

7.2.3 PHYTOVOLATALIZATION- Absorption of contaminants from the soil by the plants, their upward movement and then release from the aerial parts

7.2.4 PHYTODEGRADATION- Use of plant roots and associated microbes to degrade the pollutants present in the soil

7.3 CHEMICAL REMEDIATION

Chemical remediation involves chemical fixation, chemical leaching, vitrification and electrokinetic remediation etc.

7.3.1 CHEMICAL LEACHING- Washing of contaminated soils with reagents, fluids, water and gases that helps the pollutant to leach out from the soil.

7.3.2 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.

7.3.3 ELECTROKINETIC REMEDIATION- Application of high voltage to the soil for removal of metal

7.3.4 VITRIFICATION- Heating of the soil at very high temperature of 1400-2000°C so that the pollutant gets volatilize or decompose.

7.4 ANIMAL REMEDIATION

Some soil living animals such as maggots, earthworms, etc. can take heavy metals in the soil. Wang et al. (2007) reported that when the concentration of Cu was low in the soil, the secretion of earthworms could promote the absorption of Cu by ryegrass.

7.5 MICROBIAL REMEDIATION

Microbial remediation refers to using some microorganisms to perform the absorption, precipitation, oxidation and reduction of heavy metals in the soil.

According to Siegel et al. (1986), fungi could secrete organic acids, amino acids and other metabolites to dissolve heavy metals. Fred et al. (2001) suggested that the *Gomus intraradices* fungi, may improve the absorption and tolerance of sunflower to Cr.

8. CHALLENGES RELATED TO REMEDIATION TECHNOLOGIES

The remediation technologies described above are time consuming; costly and labour consume method, 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 surfactants and chelating agents 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.

9. CONCLUSION

Because of rapid industrial revolution in current century, terrific and undesirable effects on different sectors have been observed which are not only altering the sectors sequences but also causing humans and animals health hazards in their long term association. Certain metals in their trace values are essential but their higher values have deleterious effects. There are several reasons for heavy metal contamination in agricultural soils but discharge of industrial raw or treated sewage on soil appears as a major cause of heavy metal contamination. It seems very essential to find out some potent microbial strains for degradation of different heavy metals and also efforts should be made to optimize the different conditions to accelerate the transformation or degradation of heavy metals. Biotechnological approaches should be taken to enhance microbial degradation efficiency. There is an urgent need to prevent disposal of effluents on agricultural and forest land. To make assurance free from contamination of soil, it is imperative to prevent disposal of treated effluents because it may cause severe human health hazard if it is translocated in the product. Therefore regular monitoring of treated effluents is the need of the hour for human welfare.

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