Heavy metal polluted soil: A review on heavy metal contaminations and their toxic effects

[1]Alice Keerthana S., [2]Kiruthika S., [3]Aparna N.R., [4]Sundar M., [5*]Kandasamy Arungandhi

1,2,3,4,5, – Postgraduate students, 6 – Associate Professor

PG and Research Department of Biotechnology, Dr. N.G.P Arts and Science College (Autonomous), Coimbatore – 641048.

Abstract:

The pollution of the environment with toxic heavy metals is spreading throughout the world due to the global industrial progress. The heavy metals released from the industries causes several ailments in both plants, animals and human beings. The heavy metals are the metals and metalloids possessing biological toxicity that inhibits the growth of beneficial microorganisms that are present in the soil. The release of toxic heavy metals into the environment occurs through the industries. The most common heavy metals are lead (Pb), nickel (Ni), Chromium (Cr), Cadmium (Cd), Arsenic (As), Mercury (Hg), Zinc (Zn) and Copper (Cu).

Key words: Heavy metal polluted soil, cadmium, lead, arsenic, mercury, zinc, remediation.

Introduction:

Due to the increase in pollution, rapid urbanization and industrialization the essential elements of life such as air, water and land are constantly getting contaminated (Chikkara. S and Dhankar. R 2008). Of these heavy metal pollutions of soil and waste water is a significant problem (Cheng. S 2003). Several guidelines were being framed by many countries for the presence and exposure of heavy-metals as well as bioremediation. To prevent the over consumption of heavy metals frequent screening of soil and water resources were conducted. (Li J et al., 2006). Although heavy metals are naturally present in the soil, geologic and anthropogenic activities increase the concentration of these elements to amounts that are harmful to both plants and animals (B.J. Alloway 1990). Some of these activities include mining and smelting of metals, burning of fossil fuels, use of batteries and other metal products (I. Raskin et al., 1994, Z. Shen 2002).

There are different sources of heavy metals in the environment such as: natural, industrial, domestic, agricultural and atmospheric sources. Activities such as mining, electroplating, metallurgical, smelting operations have contaminated the soil and water resources (Herawati et al., 2000). Heavy metal pollution is a major environmental problem (Azavedo R.V. et al., 2009). Unlike organic contaminants, metals do not degrade and remain in the environment for a long period of time; when present at high concentrations, metals can negatively affect the plant metabolism (P. Ferraz et al., 2012). Heavy metals contaminated soil causes health hazards to plants, animals and even human beings (Robin et al., 2004)

Cadmium (Cd), the heavy metal is nonessential but it is considered as poisonous for plants, animals and humans (Gupta and Gupta, 1998), Lead (Pb) a major pollutant found in soil is hazardous and highly toxic to human, animals, plants and microbes (Low et al., 2000). Nickel (Ni) is the 24 th abundant element that has both the soft and hard metal properties (Costa and Klien, 1999). Ni has been found to be an embryo toxin as well as a teratogen (Chen and Lin,1998). Hexavalent chromium (Cr (VI)) and trivalent chromium (Cr (III)) are the most prevalent species of chromium (Chung et al., 2006).

Different microbes have been proposed to be efficient and an economical alternative in removing the heavy metals (Waisberg et al.,). Plants take up heavy metals by absorbing them from the deposits on the parts of the plants exposed to the contaminated soils (Choudhury P. et al., 1998). The toxic effects of heavy metals on microorganisms are influenced by multiple of factors such as pH, concentration of chelating agents, speciation and organic matter (Duxbury T, Ugoji E.O et al., Misra T.K et al.,).

Heavy metal polluted soil:

Heavy metals are also the type of elements that can exhibit various types of metallic properties like conductivity, cation stability, malleability and ligand specificity. (Raskin P.B et al.,). The metal pollution can be increased in the soil due to metal plating, coal-based waste, mining by product, chemical, industrial, nuclear and pesticide waste, mineral leaching and gasoline (Schwartz C et al., Passariello B et al., Halbich TFJ et al.,)

The emissions of heavy metals into the environment occurs spontaneously in a wide range of processes and pathways, including to the air (*e.g.* during combustion, extraction and processing), to surface waters (*via* runoff and releases from storage and transport) and to the soil (and hence into groundwaters and crops). The main threats regarding the heavy metals that affect the human health are associated with the exposure to lead, cadmium, mercury and arsenic (Berglund M et al.,).

Metal mining and milling process:

Mining and milling of metal ores along with the industries have affected many countries due to the wide distribution of metal contaminants in soil. During mining, the metals are directly discharged into natural depressions, including onsite wetlands resulting in elevated concentrations (P. S. DeVolder). Extensive accumulation of Pb and Zn have resulted in contamination of soil that poses risk to human and ecological health (N. T. Basta and R. Gradwohl). Other heavy metals are generated by industries such as textile, tanning, accidental oil spills from petrochemicals. Although some are disposed of on land, yet few have some benefits on agriculture and forestry. Many soils are potentially hazardous because of the heavy metal contaminants such as Cr, Pb, and Zn (M. E. Sumner).

Potential risk of heavy metals:

The most common heavy metals found at the site of contamination are Pb, Cr, As, Zn, Cd, Cu, and Hg (USEPA, Report). These metals are important because they have the capacity of decreasing the crop production by causing changes in bioaccumulation and biomagnification in the food chain. The groundwater contamination is also very high. Knowledge of the basic chemistry, environmental and associated health effects of these heavy metals is necessary in understanding their speciation, bioavailability, and remedial options. The transport of a heavy metal in soil depends significantly on the chemicals and specifically on the metals. In the soil, the heavy metals are generally adsorbed by initial fast reactions between few hours to minutes, which is followed by slow adsorption reactions between days and year. These are therefore, redistributed into various chemical forms with variations in bioavailability, mobility, and toxicity (J. Shiowatana et al., and J. Buekers). This distribution of heavy metals are controlled by reactions of heavy metals present in the soils such as mineral precipitation and dissolution, ion exchange, adsorption, and desorption, aqueous complexation, biological immobilization and mobilization, and plant uptake (Elinder CG et al.,).

Cadmium:

Cadmium occurs naturally in ores along with zinc, lead and copper. Cadmium compounds are used as stabilizers that stabilizes several products such as PVC pipes, colour pigments and several alloys. Now it also stabilizes re-chargeable nickel–cadmium batteries. Metallic cadmium can be used as an anticorrosion agent (cadmiation). It is used as a pollutant in phosphate fertilizers. Cadmium rich products are rarely re-cycled, but they are frequently dumped together with domestic wastes which in turn causes environmental pollution (Jarup L et al.,).

Health effects of cadmium:

The inhalation of cadmium fumes or cadmium particles can be life threatening, but acute pulmonary effects and deaths are uncommon, (Jorgensen N et al., Prince TSet al.,). Cadmium exposure may lead to kidney damage. The first sign of the renal lesion is obtained usually by a tubular dysfunction, which is evidenced by an increased excretion of the low molecular weight proteins [such as β2-microglobulin and α1-microglobulin (Vahter M et al., WHO). Several reports have since shown that the kidney damages are likely to occur due to the lower kidney cadmium levels (Roels Het al.,).

Lead:

Lead (Pb) is a naturally occurring, bluish grey metal found as a mineral combined with other elements, such as sulphur (i.e., PbS, $PbSO_4$), or oxygen ($PbCO_3$), and ranges greatly from 10 to 30 mg kg-1 in the earth's crust (USDHHS). The human population is being exposed to lead from air and food approximately in equal proportions. High levels of air emissions from the lead mines and smelters can pollute the nearby areas. Airborne lead can be deposited on soil and water, thus reaching humans *via* the food chain (WHO). In addition to the inorganic compounds of lead, there are also a number of organolead compounds such as tetraethyl lead available. Inhalation and ingestion are the major two routes of exposure into the humans and the effects from both are the same. Accumulation of Lead (Pb) in the body organs (i.e., brain), may lead to poisoning (plumbism) or even death, Lead Poisoning (D. R. Baldwin et al.,)

Health effects of lead:

Lead is generally not an essential element instead it is a well-known ecology to be toxic and its effects are extensively reviewed than the effects of other trace metals. Lead (Pb) can cause a serious injury to the brain, nervous system, red blood cells, and kidneys (D. R. Baldwin et al.,). Repeated exposure to lead results in a wide range of biological effects depending upon the level and duration of exposure. There is no essential function of lead in the human body, it can merely harm after uptake from food grown in the polluted soil, air, or water. Lead is a particularly a dangerous chemical, as it accumulates in the individual organisms, but also affects the entire food chains. The most serious source of exposure of the soil lead into the human is through direct ingestion (eating) of contaminated soil or dust. In general, plants do not absorb or accumulate lead into it. However, in soils testing, it is possible for some lead to be taken up by the plants. Lead do not readily accumulate in the fruiting parts of vegetable and fruit crops (e.g., corn, beans, squash, tomatoes, strawberries, and apples). Higher concentrations of lead are found to be in leafy vegetables that are grown in polluted soils with total lead level less than 300 ppm. The risk of lead poisoning through the food chain increases as the polluted soil lead level rises above this concentration. Even at soil levels above 300 ppm, most of the risk of lead accumulation is from the lead contaminated soil or dust deposited on the plants rather than from the lead uptake by the plant (C.J. Rosen)

Arsenic:

Arsenic is a widely distributed metalloid that is occurring in rock, soil, water and air. Inorganic arsenic is greatly present in groundwater used for drinking in several countries all over the world. Whereas the arsenic compounds (such as arsenobetaine) are primarily found in fish, which thus may give rise to human exposure. Absorption of arsenic in airborne particles is highly dependent on the solubility and the size of particles. Soluble arsenic compounds are easily absorbed from the gastrointestinal tract. However, inorganic arsenic is extensively methylated in humans and the metabolites are excreted in the urine. The concentration of arsenic in blood, hair, nails and urine have been used as the biomarkers of exposure (WHO).

Health effects of Arsenic:

Inorganic arsenic is acutely toxic. The intake of large quantities of arsenic leads to gastrointestinal symptoms, severe disturbances of the cardiovascular and central nervous systems, and eventually may lead to mortality. In general, bone marrow depression, haemolysis, hepatomegaly, melanosis, polyneuropathy and encephalopathy may be observed. The Ingestion of inorganic arsenic may also induce peripheral vascular disease, the human Populations exposed to arsenic *via* the drinking water show excessive risk of mortality from lung, bladder and kidney cancers. There is also another increased risk of ailment that is the skin cancer and other skin lesions, such as hyperkeratosis and pigmentation changes. The concentration of arsenic in drinking water is approximately 100 µg/l have led to cancer, and the precursors of skin cancer have been associated with the levels of 50–100µg/.

Mercury:

Mercury is potentially a toxic element found in the soil (Alloway 2013; Raju et al. 2019). If once mercury is liberated into the atmosphere from various sources such as ores, industries etc, it will get deposited to the soil and water surface. (Xu et al. 2015). Mercury can be liberated into the environment through the natural and anthropogenic source. The natural means occurs through the volcanic and geothermal activities (Martín and Nanos 2016, Gustin 2003).

Health effects of Mercury:

Due to the repeated exposure mercury induces the oxidative stress and mitochondrial disinfection and causes change in the DNA (Wang and Jia). Exposure to acute mercury causes lung and kidney damage (Lindh et.al.,).

Zinc:

Zinc occurs naturally in the soil in crustal rocks (Davies and Jones). Moat Zn is added to the environment during the industrial activities such as mining, coal, waste combustion and steel processing. Zinc can interrupt the activity in soils, as it negatively influences the activities of microorganisms and earthworms (K.M. Greany) Zinc occurs naturally in soil, air and water. The concentration of Zinc is rising unnaturally, due to addition of zinc to the environment through human activities. Some soils are heavily contaminated with zinc, and these are to be found in places where zinc has to be mined or refined, or were sewage sludge from industrial areas has been used as fertilizer (Marques et al.,).

Health effects of Zinc:

Though humans can handle a large concentration of zinc proportionally, too much zinc liberation still causes eminent health problems, such as stomach cramps, skin irritations, vomiting, nausea and anaemia. Very high levels of zinc can damage the pancreas and disturb the protein metabolism. Extensive exposure to zinc can cause respiratory disorders in humans.

Remediation of the heavy-metal polluted soil:

The objective of any soil remediation approach is to create a final solution that is protective for both the human health and the environment (T. A. Martin and M. V. Ruby). Remediation is generally an array of regulatory requirements based on assessments of human health and ecological risks. The regulatory authorities will accept the remediation strategies that concentrates on reducing the metal bioavailability. In case of the heavy metal-contaminated soils, the physical and chemical form of the heavy metal contaminant in soil influences on the selection of the appropriate remediation treatment. Information about the physical characteristics. (T. A. Martin and M. V. Ruby).

The contaminated soil should be characterized to identify the type, amount, and distribution of heavy metals in the soil. Once after the site has been characterized, the desired level of each heavy metal in soil must be determined. This is obtained by the comparison of observed heavy metal concentrations along with the soil quality standards for a particular regulatory domain available. Remediation goals for heavy metals are considered as the total metal concentration or as leachable metal concentration in the soil, or as some combination of these both. Several technologies have been found for the remediation of metal contaminated soil. (S. K. Gupta et al.,).

The remediation process in general includes (i) the gentle *in situ* remediation, (ii) the *in situ* harsh soil restrictive measures, and (iii) the *in situ* or *ex situ* harsh soil destructive measures. The goal of the last two alleviating measures is to remove and reduce the hazards that affect either man, plant, or animal while the main goal of the remediation process is the *in situ* remediation that restore the soil fertility which in turn allows a safe use of the soil. At present, a variety of approaches have been obtained for remediating contaminated soils. The remediation technologies for contaminated soils are broadly classified into source control and containment remedies. Source control involves *in situ* and *ex situ* treatment technologies for the contaminated source of soil. *In situ* or in place means that the treatment of contaminated soil in its original place; unmoved, unexcavated; remaining at the site or in the subsurface. *Ex situ* means that the contaminated soil is moved, excavated, or removed from the site or subsurface. Implementation of *ex situ* remedies requires excavation or removal of the contaminated soil. (USEPA).

The key factors that may influence the applicability and selection of the available remediation technologies are: cost, long-term effectiveness commercial availability, general acceptance, applicability to high metal concentrations, applicability to mixed wastes heavy metals and organics, toxicity reduction, mobility reduction, and volume reduction. (J. Shiowatana et al.,)

Conclusion:

Background knowledge of the sources, presence and potential risks of toxic heavy metals in the contaminated soils is necessary for the selection of appropriate remediation process. Remediation of the soil contaminated by the heavy metals are necessary in order to reduce the associated risks to the living organisms, to equip the land resources for the agricultural production, to enhance the food security, and to put down land tenure problems. Immobilization, soil washing, and remediation are frequently noticed among the best available technologies for removing up the heavy metal contaminated soils but are mostly used in the developed countries. These technologies need the field applicability and commercialization in the developing countries which in turn enhances the agriculture, urbanization, and industrialization.

Recent data indicate that adverse effects of heavy metals exposure on human health, primarily from the renal tubular damage but also effects on the bone and fractures due to the lower exposure levels than exposed previously. Although lead in petrol has dramatically declined over the last decades, the reduction in the environmental exposure of lead additives should be reduced Long-term exposure of arsenic in drinking water is related to increased risks of skin cancer, and also some other cancers, and other skin lesions such as hyperkeratosis and pigmentation changes. The occupational exposure to arsenic inhalation is associated with lung cancer.

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50. Speciation of zinc in contaminated soils Chadi H.Stephan[a] FrançoisCourchesne[b] William H.Hendershot[c] Steve P.McGrath[d] Amar M.Chaudri[d] ValérieSappin-Didier[e]SébastienSauvé