# IMPACT OF TOXIC METALS LEADING TO ENVIRONMENTAL POLLUTION

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**ABSTRACT**

Mining, manufacturing, and the use of synthetic products (e.g. pesticides, paints, batteries, industrial waste etc) can result in heavy metal contamination of urban and agricultural soils. The presence of heavy metals in the environment (soil or water) poses serious risks and hazards to the ecological balance and human health. The food chain (soil->plant->human or soil->plant->animal->human) and drinking water are directly affected as a consequence of heavy metal contamination. For instance,

Metals like lead (Pb) affect the nervous system, chromium (Cr) causes skin allergies, whereas Arsenic (As) and nickel (Ni) are associated with increased risk of cancer. The major threat imposed by cadmium (Cd) and mercury (Hg) is chronic accumulation in the kidneys leading to kidney dysfunction. While these are all the direct consequences of heavy metal contamination on human health, the indirect losses include (a) reduction in food quality via phytotoxicity and (b) reduction in land usability for agricultural

Hence, it is necessary to develop novel ‚soil remediation techniques' based on biological species. Scientific research has demonstrated that naturally occurring biological species such as microorganisms and even plants (of some kind) may be used for the purpose of soil remediation. For instance, a type of bacteria called Methanotrophs (or Methanotrophic bacteria) releases a compound namely, Methanobactin which binds with metallic contaminants in the soil. In addition to reducing the concentration of metals in the soil, Methanotrophs also absorb poisonous methane gas from the environment and converts it into methanol in the presence of oxygen. Some plants also actively take part in fighting the heavy metal contamination of soil. For example, in a process termed as ‚Phytoremediation', plants are used to stabilize or remove metals from soil and water. The three mechanisms used are phytostabilization, rhizofiltration and phytoextraction.

**Key words:** Phyto extraction, phytostabilization, rhizofiltration and phytoextraction

## 1. INTRODUCTION

Heavy metal contamination of soil and water poses serious risks to human life. The risk assessment and management of heavy metals is far more complicated than that of organic chemicals because the latter tend to degrade with time, whereas heavy metals do not degrade and they exist in the soil forever, unless treated appropriately. The sources of toxic metals in the ground and water are plenty. Modern activities such as mining, industrial processes and manufacturing, and the use of synthetic products (e.g. pesticides, paints, batteries and the disposal of industrial and domestic sludge) result in heavy metal contamination of urban and agricultural soils. Heavy metals also occur naturally, but rarely at toxic levels. Potentially contaminated soils may occur at old landfill sites (particularly those that accepted industrial wastes), old agricultural lands that used insecticides containing arsenic as an active ingredient, fields that had past applications of waste water or municipal sludge, areas in or around mining waste piles, industrial areas where chemicals may have been dumped on the ground and so on (S. Khan, 2008; M. K. Zhang, 2010; GWRTAC, 1997). The objective of this article is to demonstrate the deleterious effects of toxic metals on the crop and human health and to provide some interesting methods to fight heavy metal contamination of soil. Special emphasis has been devoted to address contamination of soil by Copper. This is because of the burgeoning usage of electronic devices in the modern civilization.

## 2. IMPACT OF TOXIC METALS ON ENVIRONMENT AND HEALTH

Different metals show different impacts on the environment and health. Hence it is necessary to first identify the nature of soil contamination in order to reduce it effectively. Excess heavy metal accumulation in soils is toxic to humans and other animals. Exposure to heavy metals is normally chronic (exposure over a longer period of time), due to food chain transfer. Acute (immediate) poisoning from heavy metals is rare through ingestion or dermal contact, but is possible. Some of the chronic problems associated with long-term heavy metal exposures are:

**Table 1**: Impact of various toxic metals on human health (or environment) (D. R. Baldwin, 1999; A. Scragg, 2006).

| Metal | Impact |
|---|---|
| Arsenic (As) | Leads to skin poisoning and cancer. Also affects kidneys and central nervous system |
| Cadmium (Cd) | Affects kindeys and liver |
| Chromium (Cr) | Causes skin allergies |
| Copper (Cu) | Lowers the crop yields |
| Lead (Pb) | Affects nervous system. Causes mental Lapse |
| Mercury (Hg) | Chronic accumulation in the kidneys leading to kidney dysfunction |
| Nickel (Ni) | Increases the risk of cancer |

In addition to the metallic elements presented in the above table, other harmful metals include zinc (Zn), molybdenum (Mo), boron (B) etc. While the direct harmful effects of different heavy metals are listed in the table above, the indirect losses include (a) reduction in food quality via phytotoxicity and (b) reduction in land usability for agricultural production causing food insecurity. It is worthwhile to note that PREVENTION IS BETTER THAN CONTROL, which is also applicable in the present context. Once metals are introduced into environment, they cannot be removed easily. It takes a lot of time, energy and money to purify soil from the toxic metals. Hence, the best remedy is to avoid heavy metal accumulation in soil or water by properly treating the industrial waste, without allowing them to contact soil or water. However, if the soil is already contaminated, the resulting undesired consequences can be controlled by applying various purification techniques that involve plants, micro-organisms or chemicals as active cleaning agents. However, the usage of chemicals may solve some problems, but may again create more. Hence, in the next two sections of this article, it has been shown how plants and micro-organisms can be used to tackle this problem in a more biological way, rather than with chemicals.

**3. REMEDIES**

**3.1 Phytoremediation:** Research has demonstrated that plants are effective in cleaning up contaminated soil (Wenzel, 1999). Phytoremediation is a general term for using plants to remove, degrade, or contain soil pollutants such as heavy metals, pesticides, solvents, crude oil, polyaromatic hydrocarbons, and landfill leacheates. Plants have been used to stabilize or remove metals from soil and water. The three mechanisms used are rhizofiltration, phytoextraction and phytostabilization.

**3.1.1. *Rhizofiltration:*** Rhizofiltration is the adsorption onto plant roots or absorption into plant roots of contaminants that are in solution surrounding the root zone (rhizosphere). Rhizofiltration is used to decontaminate groundwater. Plants are grown in greenhouses in water instead of soil. Contaminated water from the site is used to acclimate the plants to the environment. The plants are then planted on the site of contaminated ground water where the roots take up the water and contaminants. Once the roots are saturated with the contaminant, the plants are harvested including the roots. In Chernobyl, Ukraine, sunflowers were used in this way to remove radioactive contaminants from groundwater (A. Scragg, 2006).

**3.1.2. *Phytostabilization:*** Phytostabilization is the use of perennial, non-harvested plants to stabilize or immobilize contaminants in the soil and groundwater. Metals are absorbed and accumulated by roots, adsorbed onto roots, or precipitated within the rhizosphere. Metal-tolerant plants can be used to restore vegetation where natural vegetation is lacking, thus reducing the risk of water and wind erosion and leaching. Phytostabilization reduces the mobility of the contaminant and prevents further movement of the contaminant into groundwater or the air and reduces the bioavailability for entry into the food chain.

**3.1.3. *Phytoextraction:*** Phytoextraction is the process of growing plants in metal contaminated soil. Plant roots then translocate the metals into aboveground portions of the plant. After plants have grown for some time, they are harvested and incinerated or composted to recycle the metals. Several crop growth cycles may be needed to decrease contaminant levels to allowable limits. If the plants are incinerated, the ash must be disposed of in a hazardous waste landfill, but the volume of the ash is much smaller than the volume of contaminated soil if dug out and removed for treatment.

Phytoextraction is carried out with plants called hyperaccumulators, which absorb unusually large amounts of metals in comparison to other plants. Hyperaccumulators contain more than 1,000 milligrams per kilogram of cobalt, copper, chromium, lead, or nickel; or 10,000 milligrams per kilogram (1 %) of manganese or zinc in dry matter (Baker, 1989). One or more of these plant types are planted at a particular site based on the kinds of metals present and site conditions. The following example table (Table 2) demonstrates the real-life observations of the reduction in the concentrations of zinc and cadmium in different soils with the growth of hyperaccumulators.

**Table 2: Percentage decrease in water-extractable zinc and cadmium in three soils after growth of Alpine pennycress (Thlaspi caerulescens)**

| Site sampled | Zn | Cd |
|---|---|---|
| Farm | 28 | 10 |
| Garden | 17 | 22 |
| Mountain | 64 | 70 |

Phytoextraction is easiest with metals such as nickel, zinc, and copper because these metals are preferred by a majority of the 400 hyperaccumlator plants. Several plants in the genus Thlaspi (pennycress) have been known to take up more than 30,000 ppm (3%) of zinc in their tissues. These plants can be used as ore because of the high metal concentration (Brady, 1999). Among all the metals, lead is the most common soil contaminant (U.S. EPA, 1993). Unfortunately, plants do not accumulate lead under natural conditions. A chelator such as EDTA (ethylenediaminetetraacetic acid) has to be added to the soil as an amendment. The EDTA makes the lead available to the plant. The most common plant used for lead extraction is Indian mustard (Brassisa juncea). Phytotech (a private research company) has reported that they have cleaned up lead-contaminated sites in New Jersey to below the industrial standards in 1 to 2 summers using Indian mustard (Watanabe, 1997). Plants are available to remove zinc, cadmium, lead, selenium, and nickel from soils at rates that are medium to long-term, but rapid enough to be useful. Many of the plants that hyperaccumulate metals produce low biomass, and need to be bred for much higher biomass production.

**3.2 Role of bacteria in removing toxic metals:** As mentioned earlier, soil contamination by copper takes place from electronic devices and fungicides industries. The average copper concentration in soil ranges from 2 to 40 mg/kg, but in contaminated soils the concentration can exceed 1000 mg/kg (Scheffer, 2002). A concentration above 20 to 35 mg/kg leads to first symptoms in plants like browning of leaves or less growth and lower crop yields. It is interesting to note that a type of bacteria, named as Methanotrophic bacteria (or simply Methanotrophs) plays an active role in reducing copper concentration from the contaminated soil. There are three types of Methanotrophs which are distinguished from one another by the characteristic pattern of their internal membrane systems. Type 1 is characterized by stacked bundles of disc-shaped membranes through the centre of the cell, Type 2 contains peripheral rings of membranes. Type X is a mixture of Type 1 and Type 2. They have the same membrane design like Type 1 methanotrophs but some physiological characteristics of Type 2 (Hanson, 1991). In aerobic environments, methanotrophic bacteria oxidize methane with oxygen, thus producing methanol and water. This reaction is catalyzed by a specific enzyme called methane monooxygenase (MMO). These enzymes again exist in two types: (a) particulate methane monooxigenase (pMMO), which is bound to the membrane and (b) soluble methane monooxigenase (sMMO), which is present in the cytoplasma of some species. Usually in the environments that are rich in copper, pMMO builds up preferentially. This enzyme was found to contain a copper binding compound, called Methanobactin. Latest results showed that methanobactin can not only acquire copper but also has a high affinity to other metals. Thus, a better understanding of these enzymes and their chemical compounds will enable the Methanotrophis bacteria to reduce other metallic species also, in addition to copper. The structure of methanobactin (shown below in Figure 1) has recently been described with the stoichiometric formula $C_{45}N_{12}O_{14}H_{62}Cu$. It has a pyramidal geometry with a copper ion located at the base and coordinated by two nitrogen and two sulphur atoms. This Methanobactin compound has the ability to reduce Cu (II) to Cu (I) [14]. For easier understanding, if Cu (II) is added to purified methanobactin, it disappears in less than 10 minutes (Hakemian, 2005). The exact mechanism of the copper reduction in methanobactin has not yet been clearly determined (Choi, 2006b) which forms the basis for future research.

Thus, methanobactin acts as a defense system in case of high copper concentrations. It has been found that methanobactin is not only able to bind copper, but also other metals if copper is not available. Additionally, they consume the highly climate-active methane. Further, methanotrophs may contribute to the transport of carbon dioxide into oceans by methanobactin induced silicate weathering. Thus, methanotrophic bacteria may have a very important role in the context of global warming.

**4. CONCLUSIONS**

This article highlights the use of absoultely safe, pollution-free and risk-free biological methods to overcome toxic metal contamination of soil (and/or water). Plants (Phytoremediation methods) and bacteria (Methanotrophs) can be used to combat soil contamination from heavy metals and thereby enrich the soil. Furthermore, such methods can also be used to reduce environmental pollution and thereby fight global warming. Deeper research has to be carried out to reap more benefits from such biological ways of protecting environment.

**5. REFERENCES**

Baker and R. R. Brooks, "Terrestrial higher plants which hyperaccumulate metallic elements: a review of their distribution, ecology and phytochemistry," Biorecovery, vol. 1, pp. 81–126, 1989.

Baldwin and W. J. Marshall, "Heavy metal poisoning and its laboratory investigation," Annals of Clinical Biochemistry, vol. 36, no. 3, pp. 267–300, 1999.

Brady, N.C., and R.R. Weil. 1999. The nature and properties of soils. 12th ed. Prentice Hall. Upper Saddle River, NJ.

Choi, C.J. Zea, et al. 2006b. Spectral, kinetic, and thermodynamic properties of Cu(I) and Cu(II) binding by methanobactin from Methylosinus trichosporium OB3b. Biochemistry, 45, 1442-1453.

Choi, W.E. Antholine, et al. 2005. Effect of methanobactin on the activity and electron paramagnetic reson- ance spectra of the membrane-associated methane monooxygenase in Methylococcus capsulatus Bath. Microbiology-Sgm, 151, 3417-3426.

GWRTAC, "Remediation of metals-contaminated soils and groundwater," Tech. Rep. TE-97-01,, GWRTAC, Pittsburgh, Pa, USA, 1997, GWRTAC-E Series.

Hakemian, C.E. Tinberg, et al. 2005. The copper chelator methanobactin from Methylosinus trichosporium OB3b binds cop-per(I). Journal of the American Chemical Society, 127, 17142-17143.

Hanson, A.I. Netrusov & K. Tsuji. 1991. The Prokaryotes. Springer-Verlag, New York.

Khan, Q. Cao, Y. M. Zheng, Y. Z. Huang, and Y. G. Zhu, "Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China," Environmental Pollution, vol. 152, no. 3, pp. 686–692, 2008.

McGrath, S.P. 1998. Phytoextraction for soil remediation. p. 261-287. In R. Brooks (ed.) Plants that hyperaccumulate heavy metals their role in phytoremediation, microbiology, archaeology, mineral exploration and phytomining. CAB International, New York, NY.

Scheffer, P. Schachtschabel, et al. 2002. Lehrbuch der Bodenkunde, 15. Auflage, Spektrum. Akademischer Verlag Heidelberg, Berlin.

Scragg, Environmental Biotechnology, Oxford University Press, Oxford, UK, 2nd edition, 2006.

U.S. EPA. 1993. Clean Water Act, sec. 503, vol. 58, no. 32. (U.S. Environmental Protection Agency Washington, D.C.).

Watanabe, M.E. 1997. Phytoremediation on the brink of commercialization. Environmental Science & Technology/News. 31:182-186.

Wenzel, W.W., Adriano, D.C., Salt, D., and Smith, R. 1999. Phytoremediation: A plant-microbe based remediation system. p. 457-508.

Zhang, Z. Y. Liu, and H. Wang, "Use of single extraction methods to predict bioavailability of heavy metals in polluted soils to rice," Communications in Soil Science and Plant Analysis, vol. 41, no. 7, pp. 820–831, 2010.