Heavy metal pollution of soil & its remediation

Introduction

Soils may become contaminated by the accumulation of heavy metals and metalloids through emissions from the different activities.

Heavy metals constitute an ill-defined group of inorganic chemical hazards, and those most commonly found at contaminated sites are lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), cadmium (Cd), copper (Cu), mercury (Hg), and nickel (Ni)

The presence of toxic metals in soil can severely inhibit the biodegradation of organic contaminants . Heavy metal contamination of soil may pose risks and hazards to humans and the ecosystem through:

- direct ingestion or contact with contaminated soil,
- the food chain (soil-plant-human or soil-plant-animal- human),
- drinking of contaminated ground water,
- reduction in food quality (safety and marketability) via phytotoxicity,
- reduction in land usability for agricultural production causing food insecurity, and land tenure problems


mining
Weathering &abrasion of rocks
Agricultur e & forestry
Sources
Fossil fuels combustion
Waste disposal
Metallurgical industries

Sources of heavy metals in soil

- Fertilizers. Large quantities of fertilizers are regularly added to soils in intensive farming systems to provide adequate N, P, and K for crop growth. The compounds used to supply these elements contain trace amounts of heavy metals (e.g., Cd and Pb) as impurities, which, after continued fertilizer, application may significantly increase their content in the soil
- . Biosolids and Manures Certain animal wastes such as poultry, cattle, and pig manures produced in agriculture are commonly applied to crops and pastures either as solids or slurries . The manures produced from animals on such diets contain high concentrations of As, Cu, and Zn .
- Biosolids (sewage sludge) are primarily organic solid products, produced by wastewater treatment processes that can be beneficially recycled .

Metal mining & milling processes & industrial wastes

- During mining, tailings (heavier and larger particles settled at the bottom of the flotation cell during mining) are directly discharged into natural depressions, including onsite wetlands resulting in elevated concentrations . Extensive Pb and zinc Zn ore mining and smelting have resulted in contamination of soil that poses risk to human and ecological health. Other materials are generated by a variety of industries such as textile, tanning, petrochemicals from accidental oil spills or utilization of petroleum-based products, pesticides, and pharmaceutical facilities
- Air borne sources

It include stack or duct emissions of air, gas, or vapor streams, and fugitive emissions such as dust from storage areas or waste piles. Metals from airborne sources are generally released as particulates contained in the gas stream. Some metals such as As, Cd, and Pb can also volatilize during high-temperature processing.

chemicals	Major uses & sources of soil contamination
Arsenic	Pesticides, plant desiccants, animal feed additives, coal and petroleum, mine tailings and detergents
Cadmium	Electroplating, pigments for plastics and paints, plastic stabilizers and batteries, fertilizers
Chromium	Stainless steel, chrome–plated metals, pigments and refractory brick manufacture
Lead	Combustion of oil, gasoline, and coal; iron and steel production
Mercury	Pesticides, catalysts for synthetic polymers, metallurgy, thermometers
Nickel	Combustion of coal, gasoline, and oil; alloy manufacture, electroplating, batteries

- Lead :- atomic number 82, atomic mass 207.2, density 11.4 g cm^{-3}, melting point 327.4◦C, boiling point 1725◦C.
- naturally occurring, bluish- gray metal usually found as a mineral combined with other elements, such as sulphur (i.e., PbS, $PbSO_4$), or oxygen ($PbCO_3$), and ranges from 10 to 30 mg kg^{-1}in the earth's crust

Effects

- Pb accumulates in the body organs (i.e., brain), which may lead to poisoning (plumbism) or even death. The gastrointestinal tract, kidneys, and central nervous system are also affected. Children exposed to lead are at risk for impaired development, lower IQ, shortened attention span, hyperactivity, and mental deterioration.
- Plants tend to absorb lead from the soil and retain most of this in their roots.
- 1) Reduces the uptake of Calcium and Phosphorus 2) Exerts adverse effect on morphology and growth 3) Reduces photosynthetic activity 4) Inhibit root and stem elongation and leaf expansion

- **Chromium:**- atomic number 24, atomic mass 52, density 7.19 g cm^{-3}, melting point 1875◦C, and boiling point 2665◦C.
- one of the less common elements and does not occur naturally in elemental form, but only in compounds. mined as a primary ore product in the form of the mineral chromite, $FeCr_2O_4$

Effects

It can cause serve damage to plant:- Induces oxidative stress , Severs damage to cell membranes , Degradation of photosynthetic pigments , Decline in growth , High levels (500 ppm) of hexavalent Cr in soil reduced germination up to 48%.
Breathing high levels can cause irritation to the lining of the nose; nose ulcers; runny nose; and breathing problems, such as asthma, cough, shortness of breath, or wheezing.
● Skin contact can cause skin ulcers. Allergic reactions consisting of severe redness and swelling of the skin have been noted. ● Long term exposure can cause damage to liver, kidney circulatory and nerve tissues, as well as skin irritation.

- Arsenic:- atomic number 33, atomic mass 75, density 5.72 g cm^{-3}, melting point 817◦C, and boiling point 613◦C

Effects

1) Reduces seed germination 2) Decreases seedling height

3) Stunted growth 4) Causes Chlorosis and Wilting

5) Decreases Leaf fresh weight 6) Reduces dry matter production

cause cancers of the bladder and lungs. to high levels of inorganic arsenic are usually observed in the skin, and include pigmentation changes, skin lesions and hard patches on the palms and soles of the feet (hyperkeratosis).

“Blackfoot disease”, which is a severe disease of blood vessels

Mercury poisoning is referred to as acrodynia or pink disease.

It released into the environment by the activities of various industries such as pharmaceuticals, paper and pulp preservatives, agriculture industry, and chloroMercury has the ability to combine with other elements and form organic and inorganic mercury

. Exposure to elevated levels of metallic, organic and inorganic mercury can damage the brain, kidneys and the developing fetusine and caustic soda production industry

1. High level of Hg+2 is strongly phytotoxic to plant cells. 2) Toxic level of Hg+2 can induce physiological disorders. 3) High level of Hg+2 reduces germination and seedlings stand. 4) Induces oxidative stress by triggering the generation of ROS.

High level of Hg+2 reduces germination and seedlings stand.

Cobalt, a transition element, is an essential component of several enzymes and co-enzymes.

Effects

1) Excess of Co has adverse effect on shoot growth and biomass 2) Restrict the concentration of Fe, chlorophyll, protein 3) Reduces the catalase activity in leaves 4) High level of Co also affect the translocation of P, S, Mn, Zn 5) Restrict the transport of assimilates 6) Decrease plant sugar

Zinc Zn toxicity is the appearance of a purplish red color in leaves.

1) Decrease in growth and development

2) Induction of oxidative stress

3) Alternation of catalytic efficiency of enzymes

4) Inhibit plant metabolic functions

5) Causes senescence

6) Give rise to manganese (Mn) and copper (Cu) deficiencies Effects of Zinc on Plants

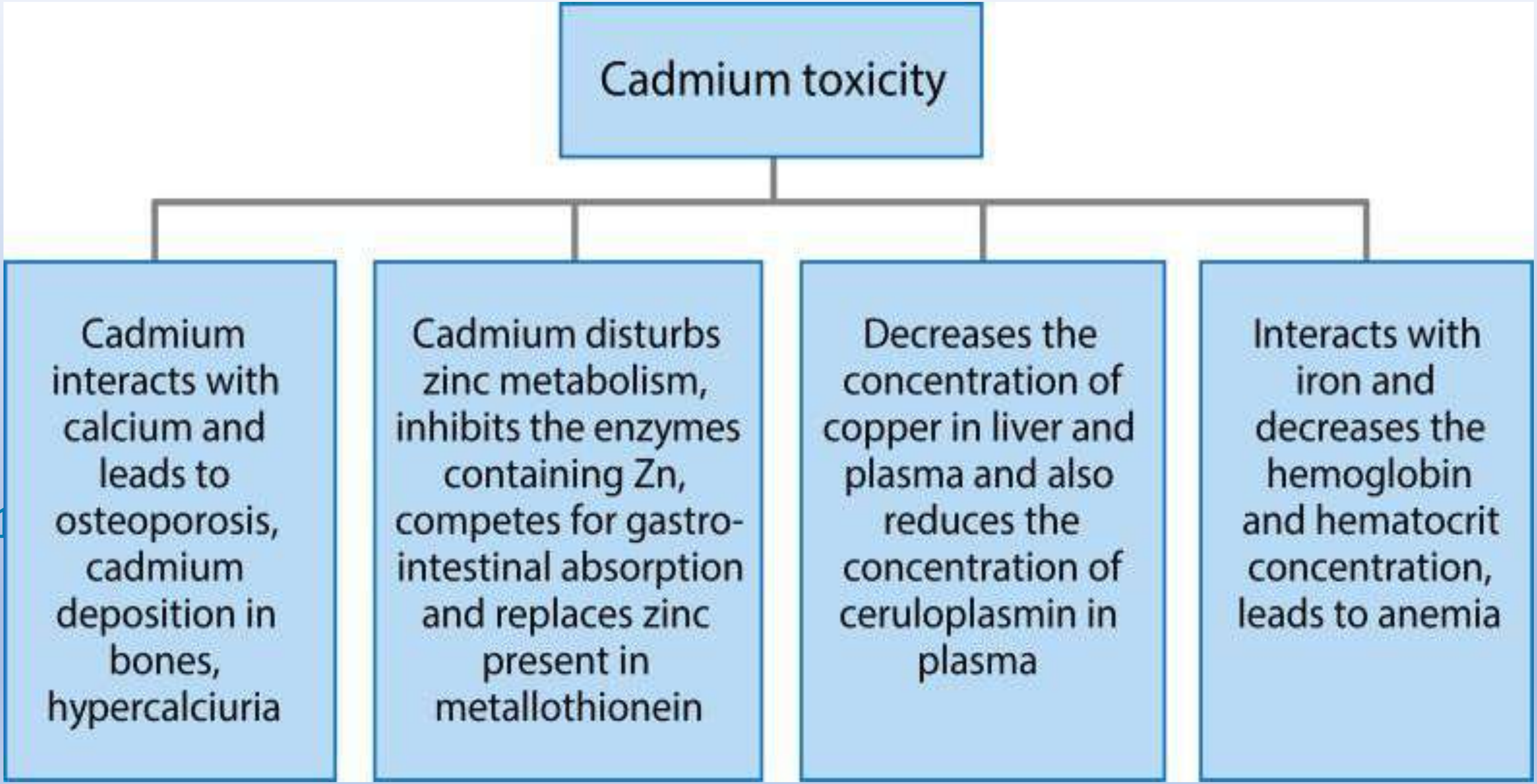
Copper is a naturally-occurring metallic element that occurs in soil at an average concentration of about 50 parts per million (ppm).

Effects

Excess of Cu in soil plays a cytotoxic role. 2) Induces stress and causes injury to plants. 3) This leads to plant growth retardation and leaf chlorosis. 4) Excess Cu generates oxidative stress 5) Copper reduces the root growth. 6) Reduces biomass and seed production. • Cu toxicity leads plant growth retardation and leaf chlorosis. • Copper reduces the root growth.

Wilson's disease is an inherited (genetic) disorder in which copper builds up in the liver.

poisoning from ingestion of excessive copper can cause temporary gastrointestinal distress with symptoms such as nausea, vomiting, and abdominal pain


Cadmium toxicity
Cadmium interacts with calcium and leads to osteoporosis, cadmium deposition in bones, hypercalciuria
Cadmium disturbs zinc metabolism, inhibits the enzymes containing Zn, competes for gastro-intestinal absorption and replaces zinc present in metallothionein
Decreases the concentration of copper in liver and plasma and also reduces the concentration of ceruloplasmin in plasma
Interacts with iron and decreases the hemoglobin and hematocrit concentration, leads to anemia

Remediation

The key factors that may influence the applicability and selection of any of the available remediation technologies are:

(i) cost

(ii) long-term effectiveness/permanence

(iii) commercial availability

(iv) general acceptance

(v) applicability to high metal concentrations

(vi) applicability to mixed wastes (heavy metals and organics)

(vii) toxicity reduction

(viii) mobility reduction

(ix) volume reduction.

PHYSICAL REMEDIATION

It includes replacement of soil and thermal desorption

In soil replacement method, the contaminated soil is partly replaced by clean soil so as to minimize the concentration of contaminant in the soil.

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.

Filtration :- A chemically modified cellulose filter paper with ethylenediaminetetraacetic acid (EDTA) is described as a device for metal remediation. The high hydrophilicity of cellulose paper associated to the strong chelating properties of the EDTA moieties for metals allow the treatment of water samples containing various metal cations, including Ag, Ni, Zn, Cd, Pb, Sn and Cu, with 90-95% removal efficiency.

CHEMICAL REMEDIATION

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.

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

electrokinetic remediation, involves the application of high voltage to the soil for the removal of metal.

vitrification involves heating of the soil at very high temperature (1400-2000°C) so that the pollutant gets volatilize or decompose.

Precipitation :-in order to increase the pH and consequently precipitate and recover the metals. The most common alkaline reagents used are limestone ($CaCO_3$), caustic soda (NaOH), soda ash (Na_2CO_3), quicklime (CaO), slaked lime ($Ca(OH)_2$) and magnesium hydroxide ($Mg(OH)_2$)

Ion exchange:- Ion exchange is the exchange of ions between two or more electrolyte solutions. It can also refer to exchange of ions on a solid substrate to soil solution. Natural and synthetic clays, zeolites and synthetic resins have been used for removal and attenuation of metals from waste

Membrane technologies:-The use of membrane technologies is very effective for that which has high concentration of pollutants. It uses the concentration gradients phenomenon or the opposite which is reverse osmosis. There are different types of membranes that are used for treatment including: ultrafiltration, Nano-filtration, reverse osmosis, microfiltration and particle filtration.

BIOLOGICAL REMEDIATION

Phytoremediation involves any of the five strategies:

Phytoextraction involves the transfer of metals from the soil to the above ground plant parts

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

Phytovolatalization involves the absorption of contaminants from the soil by the plants, their upward movement and then release from the aerial parts.

Phytodegradation involves the use of plant roots and associated microbes to degrade the pollutants present in the soil.