

MICROBIAL DIVERSITY IN HEAVY METALS CONTAMINATED SOIL & ITS CORRELATION WITH HEAVY METALS REMEDIATION

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ABSTRACT

Heavy metal pollution of soil has emerged as an environmental issue linked with various human-induced activities such as industrial activities and poor disposal practices. Soil microorganisms are involved in vital nutrient cycling processes, organic matter degradation, and health promotion to plants. The breakdown of organic matter, the cycling of nutrients, and the enhancement of plant health are all facilitated by soil microbes, particularly bacteria. Microbial communities are adversely affected by heavy metal stress because it decreases their metabolic efficiency and diversity. However, certain bacterial species possess several defence systems, like efflux metal ions, sequestration, and enzymatic reduction, for their survival and thus lessening toxicity of heavy metal poisoning. The mechanisms of microbial resistance are highlighted in this review, along with the causes and effects of heavy metal pollution on soil microbial diversity and their role in eliminating heavy metals from polluted soils.

Keywords: *Heavy metals, Soil microorganisms, Microbial diversity, Toxicity, Heavy metal pollution.*

Introduction

The estimation of soil microbe population density is crucial for understanding the microbiological processes taking place in the soil. The development of new, sophisticated techniques altered the ideas of microorganism biomass and population density. The highest concentration of bacterial cells is found in biotopes such as forest litter, sod, and upper humus layers, where the bacterial population is 5–10 times denser than the bacterial population found in mineral horizons[1]. Microfauna (nematodes and protozoa), mesofauna, macrofauna, and microscopic bacteria and fungi are all present in soils, making them most diverse microbial ecosystems on the globe[2]. Anthropogenic activities in industrial areas have the ability to pollute the soil in this ecosystem, resulting in substantial heavy metal pollution and being the main reason for the increase in pollutants [3-5]. Industries release an extensive amount of heavy metals, which can disrupt balance in ecosystem and harm humans, animals, and plants by altering the growth rate and soil environment[6]. Various statistical methods can be used to study the buildup of heavy metal contaminants in the soil. The majority of contaminants are often found in the topsoil layer. The adsorption capabilities of soil particles primarily determine the amounts of contaminants in soil. A number of factors influence the solubility of heavy metal ions in soil, including moisture content, conductivity, and pH [7]. Among all the contaminants, exposure of heavy metals into soil took place through many industrial activities such as, the transportation of raw material and scrapes, metal forging, the production of alkaline storage batteries and synthetic organic compounds [8-9].

High levels of heavy metals in soil can disbalance the microbial diversity of soil. Soil microorganisms are essential component for soil ecosystems, as these microorganisms influence soil ecosystems through their involvement in biogeochemical cycles [10]. As among all microorganisms, bacteria are the most abundant, they significantly regulate the soil environment, preserving soil structure and promoting nutrient uptake and utilisation by plants[11]. Soil bacterial communities are usually highly sensitive to heavy metal stress,

which causes bacterial protein denaturation and disruption of cell membranes [12] [13]. According to earlier research, heavy metal contamination disrupts soil structure and bacterial diversity [14] [15]. There is a strong negative connection between cadmium exposure and bacterial diversity; although Proteobacteria, Verrucomicrobia, and Nitrospirae are sensitive to cadmium, Actinobacteria were tolerant [13]. The bacterial which are tolerant to heavy metals are capable of altering the mobility and availability of heavy metals through the release of chelating agents and acidification [16]. In this review paper we are going to discuss about heavy metal contamination in soil and the impact of heavy metals pollution on microbial diversity in soil and relation between microbial diversity and heavy metals remediation.

Heavy metal pollution in soil

Heavy metal pollution is a main concern for ecosystem. Heavy metals are xenobiotic, stable, and non-biodegradable, once ingested they persist in body for longer period of time [17]. Heavy metal pollution refers to the excessive accumulation of heavy metals in soil due to human activities. These heavy metals include mercury (Hg), cadmium (Cd), lead (Pb), chromium (Cr), arsenic (As), and other metals that are biologically hazardous. Additionally, they comprise various heavy metals with specific biological toxicity, such vanadium (V), nickel (Ni), copper (Cu), zinc (Zn), stannum (Sn), and so on [18].

The soil naturally contains lead. The majority of environmental lead concentrations are caused by human activity [18]. An unnatural lead cycle has been generated due to the use of lead in petrol. Automobile engines burn lead, which produces lead salts such oxides, bromines, and chlorines. Furthermore, Pb is widely employed as a crucial industrial raw material, which causes huge quantities of solid waste containing the element to accumulate, such as in mining slag, making it a serious environmental hazard. Solid waste is frequently heaped and improperly handled, which makes it easy for heavy metal ions to leach out through rain, snow, and weathering and seriously pollute the soil. In fact, soil lead pollution has emerged as a major global environmental issue [19]. Lead poisoning causes

a number of negative consequences, including: Anaemia and disruption of haemoglobin biosynthesis; elevated blood pressure; kidney damage; miscarriages and subtle abortions; nervous system disruption; and brain damage etc [18].

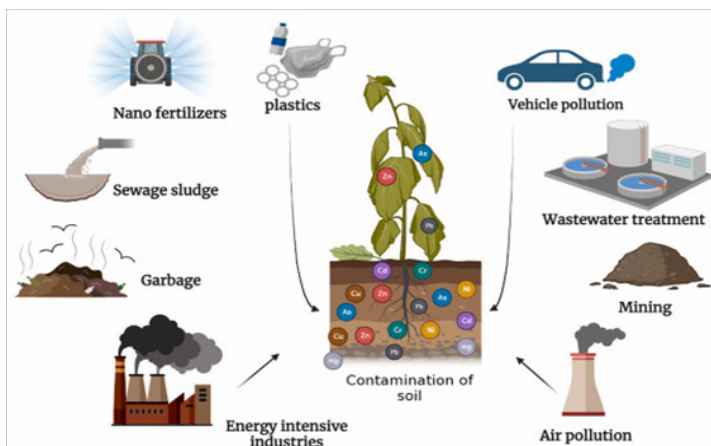


Fig 1: sources of heavy metal [20]

Microbial diversity in soil & its role

One of the most prevalent and varied biological groups in nature is the soil microbial community [21]. 1g of soil contains a variety of microorganisms, including viruses, fungus, bacteria (including actinomycetes), algae, protozoa, and archaea. Soil bacteria, the most common microbial community in soil, have great impact on biodiversity, plant health, soil texture, and the nutrient cycle [22].

As shown in FIG2, soil bacteria have the following main effects on plant growth and soil structure:

1. Bacteria contribute to the degradation of organic matter in the soil by releasing enzymes that transform organic materials into nutrients that plants can utilise. For instance, *Bacillus subtilis* and *Bacillus licheniformis* can release several proteases and polysaccharide hydrolases. A wet cellulose bacterium called *Cellulomonas uda* belongs to the *Cellulomonas* genus

and is capable of decomposing complicated macromolecular organic molecules into simpler ones. Another common use of bacteria is to decompose organic pollutants in soil. For instance, the species *Flavobacterium* is capable of decomposing phenolic chemicals and both *Pseudomonas* and *Bacillus* species are capable of decomposing polycyclic aromatic hydrocarbons (PAHs). Enhancement of soil quality, purification of the soil environment, and balancing of the soil ecosystem are all facilitated by the breakdown processes of the soil bacteria [22].

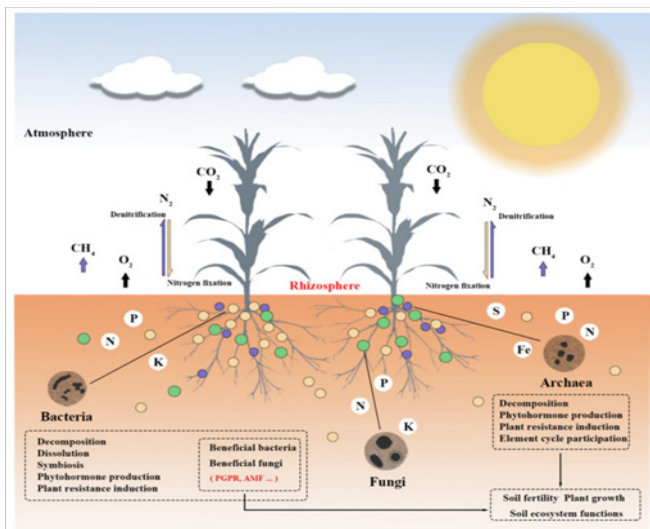


Fig2: Schematic representation of mechanisms of action of important microbial communities of soil. [22]

2. Soil bacteria facilitate the cycling of nutrients, including nitrogen, phosphorus, and potassium [22]. For example, feldspar can be broken down by *Bacillus mucilaginosus* Krass, which can also change insoluble potassium components into soluble nutrients [23] [24]. Some soil bacteria, such as those belonging to the genera *Erwinia*, *Pseudomonas*, *Agrobacterium*, and *Bacillus*, possess the capacity to transform insoluble phosphate into soluble phosphorus that plants can use, thus helps in promoting plant development[22].

3. Beneficial bacteria and plants can form symbiotic partnerships by providing nutrients that promote plant growth and development. For instance, phosphorus-solubilizing microbes form symbioses with plant roots, while *Rhizobium* forms symbioses with legume plants [22]. Nitrogen fixation [25-29] and phosphorus solubilizing actions [30-35] are the process by which they transform nitrogen and phosphorus respectively that plants cannot directly absorb into forms that they can use for growth.

4. Plant illnesses can be prevented and pathogens can be suppressed by soil microorganisms. For example, to inhibit germs, *Streptomyces* and *Bacillus subtilis* can create antibiotics. *Bacillus* can induce the production of antioxidants, antimicrobial peptides, and other compounds that help plants fight against infections and halt their spread in plants [22].

5. Plant hormones like cytokinins, gibberellins, and indole acetic acid (IAA) can be produced by some soil bacteria. By affecting physiological processes including flowering, fruit development, and plant growth, they encourage the growth of plants. Gibberellins can be produced by *Micromonospora* and *Streptomyces* [36] and IAA can be produced by PGPR-like *Bacillus* [37] [38].

6. Soil microorganisms can improve soil texture and structure. To develop polysaccharide adhesives that adhere to soil particles, help in the creation of soil aggregates, enhance soil structure, promote soil aeration and water retention, and boost soil fertility, bacteria such as *Pseudomonas aeruginosa*, *Bacillus subtilis*, and *Chromobacterium violaceum* can collaborate [39].

In conclusion, soil bacteria support plant growth, influence soil structure, and take part in ecological processes as a group. Plant and soil ecosystems are significantly impacted by their relationships with other microorganisms and plants. Together, these processes keep ecosystems stable and in balance. [22]

Mechanisms of heavymetal resistance bacteria that helps them to tolerate heavy metal toxicity

As we discussed how some bacteria are non-tolerant to heavy metal toxicity and how adversely heavy metal pollution effect those bacteria, here we are going to discuss about how somebacteria are able to tolerate heavy metal toxicity. Bacteria have adapted to withstand high amounts of heavy metals in areas near active volcanoes, hydrothermal vents, and mineral deposit sites. As a result of this adaptation, sensitive cellular components mechanisms to defend against heavy metal ions. A number of factors, including the forms of metal ion transport into the cell, the location of metal resistance genes (chromosome, plasmid, or transposon), and the function of metal ions in cellular metabolism, may affect a bacterium's ability to tolerate metals[50].

The five primary methods of bacterial resistance to heavy metals are listed by Bruins et al. and Choudhury et Srivastava. It need to be emphasized that a single bacterium may have many defence mechanisms:

- extracellular barrier;
- active transport of metal ions (efflux);
- extracellular sequestration;
- intracellular sequestration;
- reduction of metal ions; [50,51]

Extracellular barrier to stop metals from entering the cell:

Metal ions may be kept out of the cell by the cell wall, plasma membrane, or capsule. Ionizable groups of the cell wall or capsule (carboxyl, amino, phosphate, and hydroxyl groups) allow bacteria from various taxonomical groups to adsorb metal ions [52] [53]. Since metal ions can also be bound by dead bacterial cells, this adsorption is a passive process. It has been shown that the adsorption capacity of bacterial cells destroyed by heat treatment is equal to or greater than that of living cells. *Pseudomonas putida*, *Brevibacterium* sp., and *Bacillus* sp. non-viable cells showed a high degree of passive adsorption of heavy metal ions. According to several writers,

the accumulation of metal ions by living cells occurs in two stages: first, the cell wall adsorbs them quickly and non-specifically, and then the metal ions are slowly transported into the cytoplasm. Bacterial capsules have the ability to adsorb heavy metal ions, primarily through the carboxyl groups of polysaccharides. Metal ions have been found to accumulate in the extracellular biopolymers of *Enterobacter chloaceae*, *Klebsiella aerogenes*, and *Acinetobacter* sp[55].

Active transport of metal ions (efflux): Efflux, or active transport, is the most prevalent type of bacterial heavy metal resistance system. To export metal ions from cells, bacteria take advantage of these systems. The genetic determinants of efflux systems can be found on plasmids and on chromosomes. Certain metal ions can enter the cell through the mechanisms that allow critical elements to be absorbed; for instance, the sulphate transport system is used to move chromate inside the cell and the magnesium transport systems allow ions of cadmium, zinc, cobalt, nickel, and manganese to enter the cells of *Ralstonia metallidurans* (*Alcaligenes eutrophus*)[55].

Extracellular sequestration: The accumulation of metal ions by cellular constituents in the periplasm or outer membrane, or the complexation of metal ions as insoluble compounds, is known as extracellular sequestration [55].

In order to bind copper ions, copper-resistant *Pseudomonas syringae* strains produced copper-inducible proteins CopA, CopB (periplasmic proteins), and CopC (outer membrane protein) [54]. As a result of metal buildup, bacterial colonies appear blue. The similar blue bacterial colonies could be observed during growth of copper-tolerant *Pseudomonas pickettii* US321 strain on agar medium supplemented with copper, copper ions were accumulated in the periplasm or outer membrane [55].

Intracellular sequestration: When different substances in the cell cytoplasm bind with metal ions, this is known as intracellular sequestration. Two kinds of eukaryotic metal-binding peptides, phytochelatins and metallothioneins, are abundant in cysteine residues and use sulfhydryl groups to bind metal ions [56]. Plants and fungi contain peptides of

low molecular weight, called phytochelatins. They are made from glutathione and have 5 to 11 amino acid residues [57]. Among prokaryotes, the cyanobacterium *Synechococcus* sp. PCC 7942 has been shown to be capable of synthesising metallothionein. Compared to the corresponding eukaryotic peptide, this peptide has less cysteine residues. Cadmium and zinc ions cause *Synechococcus* sp. to synthesise metallothionein, which is encoded by the genes *smtA* and *smtB* [58]. Cadmium-tolerant *P. putida* strain have the capability of intracellular sequestration of copper, cadmium and zinc ions through the help of cysteine-rich low molecular-weight proteins [59].

Reduction of heavy metal ions by bacteria: Bacteria may reduce a broad range of heavy metal ions. Numerous ecological niches yielded bacteria that reduced chromate, molybdate, and vanadate [60]. Certain bacteria are able to generate energy by using metals and metalloids as electron donors or acceptors. Oxidised metals may act as terminal acceptors of electrons when bacteria are respiring anaerobically. Additionally, enzymatic reduction of metal ions would produce a less toxic form of mercury and chromium. *Bacillus cereus*, *Klebsiella pneumoniae*, *P. stutzeri* can reduce Hg^{2+} and Hg^0 from the soil. *Desulfomicrobium norvegicum*, *Microbacterium* sp., *Ochrobacterium intermedium*, *Brevibacterium* sp and *Pseudomonas* spp. Can reduce the toxicity of Cr^{6+} and Cr and reduce its availability from soil [55].

Conclusion

Heavy metal contamination has been regarded as one of the major threats to soil ecosystems as it changes microbial diversity and diminishes the quality of the soil. Microorganisms play a critical role in soil health through nutrient cycling, decomposition of organic matter, and ecosystem stabilization. Thus, the harmful impacts of heavy metals on microbial communities, which include reduced diversity and metabolic inefficiency, stress the need for effective mitigation strategies. However, certain bacteria have strong resistance mechanisms with metal ion efflux, sequestration, and enzymatic reduction. This has made it possible for the survival of these bacteria and their contribution to detoxification in heavy metals.

Utilization of these microbial capabilities opens avenues for bioremediation of contaminated soils, thereby contributing to environmentally friendly management practices. Further studies are required to fine-tune applications of microbes in remediation.

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