Metalliferous Soil Remediation Through Heavy Metal-Resistant Plant Growth-Promoting Bacteria: Prospects and Paradigms

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Basudev Majhi, Pradeep Semwal, Shashank Kumar Mishra,
Vaibhav Srivastava, Rajeev Pratap Singh,
and Puneet Singh Chauhan

Abstract

Heavy metals (HMs) are natural assets on the planet, but they have become a serious threat to environmental pollution due to fast industrial enterprise, metropolitanism, and recent technological breakthroughs. The principal causes of HMs pollution in soil, water, and air are industrial waste, organic compounds, pesticides, paints (including small-medium industries), and mining activities. The land, water, and air utilized in farming are of major significance and may have an impact on the health of living organisms. Novel and robust ecotechnologies are needed to avoid HM contamination in the environment. Microbial bioremediation has long been recognized as the most well-understood biotechnological process for environmental restoration. For the treatment of HM-contaminated environmental sites, microbial bioremediation is a cost-effective option. Researchers worldwide are making strides in discovering new bacterial strains with plasmid-linked degradation/reduction ability. Genetic engineering and molecular biology aided in the development of microbes that would produce the desired results in the environment. Recent advances in microbial bioremediation techniques include biostimulation, bioaugmentation, bioaccumulation, biosorption, and the

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B. Majhi · P. Semwal · S. K. Mishra · P. S. Chauhan (✉)
Microbial Technology Division, Council of Scientific and Industrial Research-National Botanical Research Institute (CSIR-NBRI), Rana Pratap Marg, Lucknow, Uttar Pradesh, India
e-mail: puneet@nbri.res.in

V. Srivastava
Sustainability Cluster, School of Engineering, University of Petroleum and Energy Studies, Dehradun, Uttarakhand, India

R. P. Singh
Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, Uttar Pradesh, India

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use of biofilms. This chapter assembles data on recent developments and applications of microbe-mediated bioremediation of HM-contaminated soils.

Keywords

Heavy metal · Microbial remediation · Metal toxicity

11.1 Introduction

The environment is made up of several complicated variables such as land, air, and water. The existence of humans and other living entities such as animals, plants, and bacteria is based on their positive correlation (Arora et al. 2018). Heavy metal (HM) pollution has become a serious risk to the environment and food production as a result of the massive expansion in the global population and quick progress in modern agriculture (Selvi et al. 2015). Many studies have reported it as a global problem in countries like India, Bangladesh, Italy, Germany, Greece, Hong Kong, China, Turkey, Iran, etc. (Chikumbusko et al. 2017). The lack of understanding about safe effluent disposal and the failure to impose strong regulatory standards have contributed to environmental degradation (Khalid et al. 2017). Vast amounts of solid waste in various harmful forms have been generated as a consequence of these circumstances leading to contamination of the entire ecosystem. The wastewaters, which may exceed authorized limits specified by international regulatory bodies, will have an impact on the quality of surface water and land (EPA 1992, 2002).

Because of their nonbiodegradability, bioaccumulation, environmental stability, persistence, and biotoxicity, HMs make a major environmental risk to living creatures and environments (Khan et al. 2019). They can directly affect the physical and chemical properties of the soils, air, and water, which cause environmental pollution (Fig. 11.1) (Omwene et al. 2018). They can also disrupt the natural ecosystem and have a direct and continual impact on human health through food chains, leading to various diseases (Weber et al. 2020; Suhani et al. 2021),such as paralysis agitans, Alzheimer’s, Sclerosis, cancer, hardening of the arteries, etc. (Muszyńska and Hanus-Fajerska 2015).

Many treatment approaches, such as physical, chemical, and biological, have recently been proposed to clean up HM pollution in the air, water, and soil. HM treatment processes include adsorption, heat treatment, chlorination, ion exchange, chemical extraction, bioleaching, and electrokinetics. According to reports, the majority of the aforementioned techniques are only intended to be used as single remedial methods. Despite their success, these methods have downsides such as inefficiency, cost, and failure during large-scale adoption, among other things (Volesky and Holan 1995; Selvi et al. 2019).

In this chapter, we have discussed the HM sources, their harmful effects, issues associated with the disposal and recycling of HM-containing products, and different microbial-based methods for abatement and opportunities.

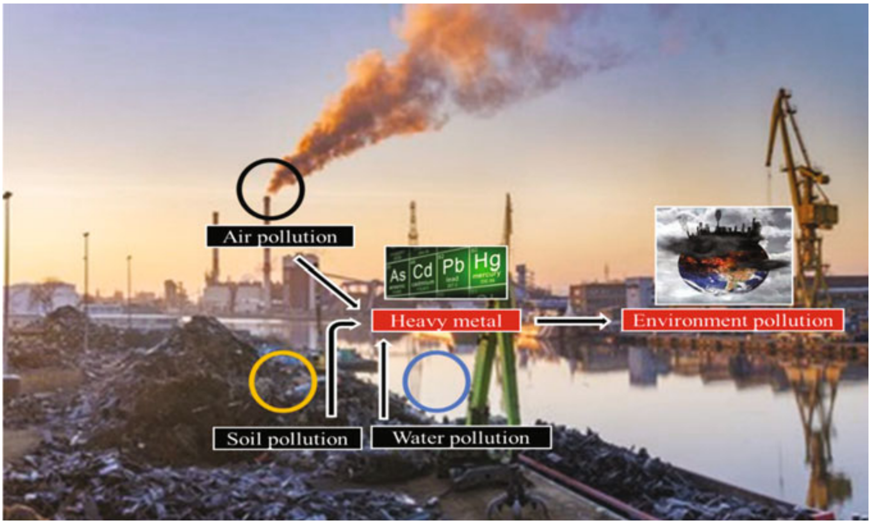

Fig. 11.1 Heavy metals cause environmental pollution

11.2 Toxicity of Heavy Metals and the Environment

The biosphere is the most significant part of the environment where biotic entities, i.e., animals and plants, interact with abiotic surroundings, viz., soil, water, and air (Mahmoudi 2003). Pollution is defined as any human action that reduces the quality of the natural environment. Pollution of the environment is nothing new, yet it is still the world's most serious problem and the primary cause of diseases and loss of life. Environmental pollution is generally worse in middle- and low-income countries as compared to the developed ones, partly due to poverty, ineffective legislation, and a lack of awareness about pollution. Environmental pollution is caused by HMs through a variety of factors, including industrial growth, urbanization, population increase, exploration, mining, deforestation, bush burning, dumping of agricultural and residential wastes in water bodies, use of pesticides in aquatic animal harvesting, inappropriate disposal of technological wastes, etc. (Landrigan et al. 2018) The repercussions affect not just people but also other land and aquatic species, including microbes, which support biogeochemical cycles required for a healthy ecosystem (Ukaogo et al. 2020).

11.3 Heavy Metals

HMs are metallic chemical elements with a relatively high density, which are harmful or lethal even at low doses. Almost all the HMs are hazardous to human health above a certain concentration and pose a risk to the environment. HMs include cadmium (Cd), zinc (Zn), molybdenum (Mo), mercury (Hg), nickel (Ni), chromium (Cr), strontium (Sr), arsenic (As), vanadium (V), boron (B), cobalt (Co), copper (Cu), molybdenum (Mo), tin (Sn), lead (Pb), etc. HMs including Cu, Ni, Fe, Zn, B, and Mo are necessary for plant growth, but when their concentrations exceed the permissible limits, they can harm animals and plants. Among all the HMs, Pb, Hg, Cd, and As are not required for the growth and development of plants and animals.

11.3.1 Sources of Heavy Metal Pollution

HMs in the soil aggregate due to a variety of causes that may be natural and anthropogenic sources (Fig. 11.2) (He et al. 2012).

11.3.1.1 Natural Sources

Under different environmental conditions, HMs are naturally emitted through volatile organic compounds, forest fire, sea-salt sprays, volcanic ash, rock depletion, and dirt particles, which are the causes of HM pollution. HMs can be found in the form of oxides, silicates, sulfides, phosphates, sulfates, hydroxides, and organic molecules. Pb, Ni, Cr, Cd, As, Hg, Se, Zn, and Cu are some of the most regularly used HMs. While these HMs are found in smaller quantities in humans and other animals, they may cause severe health concerns (Ali et al. 2021).

11.3.1.2 Anthropogenic Sources

There are a lot of anthropogenic factors of HM concentrations in the environment, but the most significant are rising industrialization and urbanization in recent days. Fertilization, pesticide application, air deposition, sewage irrigation, mining, and sludge application are responsible for HM accumulation in the environment; in addition to these factors, melting activities for metallic ores, industrial wastes, combustion of fossil fuel refinement, and refinishing contribute to HM accumulation

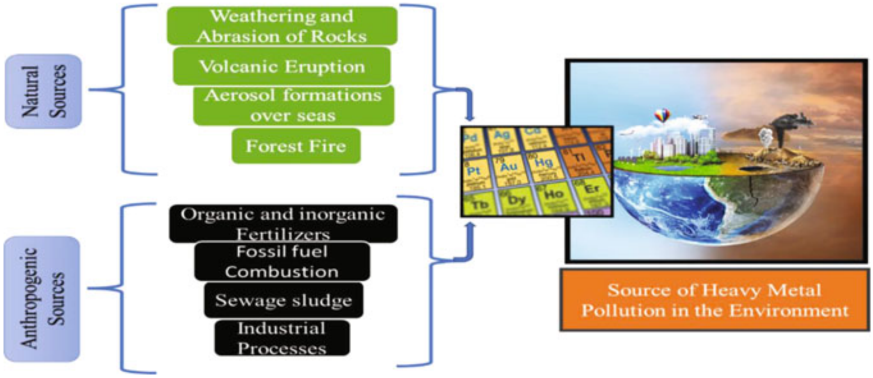

Fig. 11.2 Source of heavy metals in the environment

(Srivastava et al. 2017). The primary cause of metal pollution in the atmosphere is assumed to be coal burning (Antoniadis et al. 2017).

11.3.2 Environmental Impacts of Heavy Metals

Heavy metals have a lot of negative consequences when they are present in the environment. The hydrosphere, lithosphere, and biosphere are all affected due to these HMs (Masindi and Muedi 2018) (Fig. 11.2). They can directly impact the physical and chemical properties of the sediment, soils, and water to hinder microbial activities. They can also destabilize the natural ecosystem and have a direct and long-term impact on the human body, leading to a variety of diseases and issues in mankind (Ali et al. 2021).

Population increase is one of the major issues in the world. Due to the increasing population, the use of HMs also increased, and with this contamination, major environmental components cause serious issues worldwide (Masindi and Muedi 2018).

11.3.2.1 Effect on Soil

HMs affect the agroecosystem through both natural and artificial sources. Several studies have found that natural HM pollution sources are usually high when compared to anthropogenic activity. The parent material from which HMs are derived is the major source of HMs in soil. Human activities disrupt the nature's slow-moving geochemical cycle of HMs, resulting in accumulation in the soil (Dixit et al. 2015). Different anthropogenic activities like the refinement of fossil fuels through combustion (Muradoglu et al. 2015), smelting and extracting metals (Chen et al. 2015), municipal trash disposal (Khan et al. 2016), fertilizer application (Atafar et al. 2010), pesticide usage (Ogunlade and Agbeniyi 2011), sewage application (Sun et al. 2013; Srivastava et al. 2016), etc. cause HM pollution.

HMs in soil cause a severe problem because they accumulate in food chains, damaging the entire ecosystem. Organic pollutants are biodegradable, but their biodegradation rate is slowed by the presence of HMs in nature, which doubles the organic and HM pollution. HMs can harm animals, humans, plants, and ecosystems in a variety of ways. Direct ingestion, absorption by plants, transfer through food chains, drinking polluted water, and changes in soil color, pH, porosity, and natural chemistry all impact soil quality (Musilova et al. 2016).

11.3.2.2 Effects on Water

The kind of soil, rock, and water movement, all influence the metal composition of surface water such as rivers, lakes, and ponds. Metals on the soil's surface are carried away by the wind and end up in sewage and reservoirs (Salem et al. 2000). Rainwater becomes polluted as it travels through the atmosphere. The passage of numerous industrial wastewaters into water sources contaminates them, which contain a large number of HM leachates from landfills and liquid disposal in deep wells, and contaminates the groundwater (Oyeku and Eludoyin 2010). The metal level of water is affected by a variety of elements, including pH, life forms, ion exchange, temperature, vaporization, absorption, and others.

11.3.2.3 Effects on Air

Surface degradation and loss of colloids release HMs into the atmosphere as vapors. Mineral dust, particles of sea salt, volcanoes, and forest fires are all atmospheric sources of HMs (Colbeck 1995). HM air pollution can come from a variety of industrial activities that produce dust particles, such as metal smelters and cement factories, in addition to these natural sources. In the atmosphere, unstable metals such as gaseous pollutants particles of Sb, Se, Hg, and As are transmitted. Metals like Zn, Pb, and Cu are carried as particulates which pollutes the air (Selvi et al. 2019).

11.3.2.4 Human Exposure to Heavy Metals

Poison HMs get into the human body through a variety of mechanisms, including ingestion, inhalation, and skin absorption. People in underdeveloped countries are more exposed to hazardous metals (Eqani et al. 2016) because many people are unaware of the dangers of HM exposure and the ramifications for human health (Afrin et al. 2015). HMs may be present in the workplace and the environment. HMs are ingested by mining and industrial workers through metal particles containing dust and particulate matter. Welders exposed to welding fumes for an extended period had considerably greater blood levels of the HMs such as Cr, Ni, Cd, and Pb than the control group, as well as elevated oxidative stress (Mahmood et al. 2015). Cigarette smoking is a major source of human exposure to harmful HMs, i.e., Cd (Järup 2003) and other HMs found in tobacco leaves. Among these HMs, As is one of the most hazardous metalloids on the earth. According to the World Health Organization (WHO), the limit of As in the drinking water is 5–10 μg/L, but in many countries like Bangladesh and some parts of India, As concentration is more than 50 μg/L, causing many diseases such as skin cancers, kidney cancer, lung cancer, and bladder cancer apart from long-term exposure of inorganic arsenic hypertension, diabetes, reproductive disorders, and cardiovascular diseases (Santra et al. 2013).

The overall public is exposed to HMs through food and water. Intensification of industrial and agricultural activity has resulted from globalization, urbanization, and rapid economic development. Toxic HMs could be released into the water, air, and soil as a result of these actions. HMs bioaccumulate in human food systems, eventually reaching the human body and causing different diseases (Ali et al. 2019) (Fig. 11.3).

11.4 Environmental Heavy Metal Remediation

HMs emitted from several sites are released into the environment, either directly or indirectly, affecting humans, animals, and plants. Increased human exposure to HMs has serious health consequences and causes environmental degradation (Rzymski

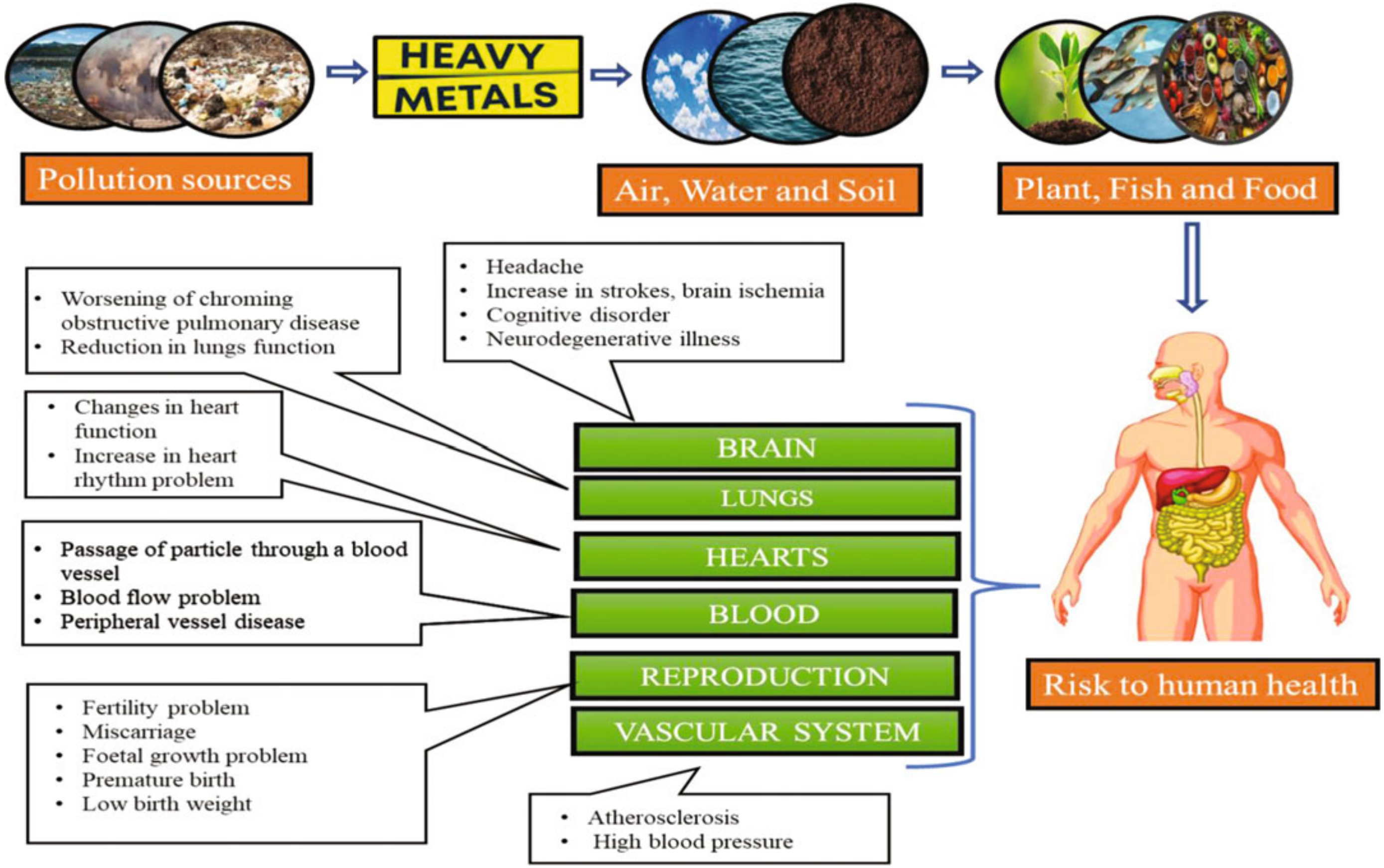

Fig. 11.3 Effect of heavy metals on human health

et al. 2014). The severity of negative health impacts varies depending on the duration of exposure, concentration, chemical form, and type of HMs. HM pollution in soil has led to ecosystem degradation, reduced food quality, and decreased soil health. HM concentrations in India's industrial zones are far greater than the WHO's allowed limit, putting humans at risk (Manivasagam 1987). The failure of respective government environmental safety agencies in developing countries to impose strict regulations and the unreliability of current individual treatment technologies in situ and a wide range of applications are all contributing to the health problems associated with metal pollution.

11.4.1 Biological Remediation

Biological remediation is the utilization of living organisms to clean up HMs in the soil. Here we mainly discussed microbial remediation and phytoremediation.

11.4.1.1 Microbial Remediation

Environmental HM contamination has seriously threatened all ecosystems (Okolo et al. 2016). According to Environmental Protection Agency, parameterization is a natural activity in which microbial processes are utilized to break down or convert dangerous substances into less harmful ones, ultimately eliminating toxins from the environment. During the microbial process, microorganisms utilize chemical pollutants as an energy source in their metabolic processes. Synthetic nutrients limit microbial development in the soil (Ahirwar et al. 2016). Microorganisms can degrade, detoxify, and decontaminate substances and even accumulate toxic organic and inorganic substances from a variety of places in the environment; some bacteria will be described biochemically, and it will be determined whether they can tolerate heavy metals like copper and zinc. In the last 20 years, bioremediation strategies have made significant advances, with the ultimate goal of efficiently restoring damaged regions in an eco-friendly and low-cost manner (Ambaye et al. 2022).

11.4.1.1.1 Bacterial Remediation Capacity of Heavy Metals

Microbial biomass contains a variety of biosorption properties that range greatly among microorganisms. However, each microbial cell's biosorption ability is determined by its pretreatment and experimental settings. Bacteria are essential bioabsorbents because of their widespread distribution, size, capacity to thrive in controlled environments, and resistance to environmental conditions (Srivastava et al. 2015). Their remarkable biosorption abilities are due to their high surface-to-volume ratios and probable active chemisorption sites on the cell wall (Mosa et al. 2016). Bacteria thrive in mixed cultures because they are more stable and survive longer (Sannasi et al. 2006). As a result, consortia are metabolically efficient for metal biosorption and more suitable for field application (Kader et al. 2007). De et al. (2008) used an *Acinetobacter* sp. bacterial consortium to decrease Cr by 78%. *B. megaterium*, *B. niger*, and *Penicillium* sp. had the greatest ability to reduce Pb (2.13–0.03 mg/L), Cr (1.38–0.08 mg/L), and Cd (0.4–0.03 mg/L), respectively.

11.4.1.1.2 Plant Growth-Promoting Endophyte-Mediated Phytoremediation

Endophytic bacteria have shown to assist host plants in adjusting to harsh soil conditions and improve phytoremediation capacity by modifying metal bioavailability in soil, increasing plant growth, decreasing metal phytotoxicity, lowering mental stress, and changing metal translocation in plants (Ma et al. 2011). These bacterial endophytes contribute to the detoxification of metal-polluted soils by improving plant metal tolerance capacity and growth and increasing uptake capacity in plants as discussed (Table 11.1).

11.4.1.1.3 Fungi Remediation Capacity of Heavy Metal

Because of their strong metal uptake and restoration capabilities, fungi are often used as biosorbents to eliminate toxic metals (Fu et al. 2012). Dead fungal biomass from *Penicillium chrysogenum*, *Saccharomyces cerevisiae*, *Aspergillus niger*, and *Rhizopus oryzae* can convert hazardous Cr (VI) to less dangerous or nontoxic Cr (Park et al. 2005). Luna et al. (2016) also reported that *Candida sphaerica* creates biosurfactants that remove Pb (79%), Zn (90%), and Fe (95%). Likewise surfactin,

Table 11.1 Microorganisms used in heavy metal remediation of contaminated sites

Class of microorganisms	Heavy metal removed	References
A. Bacteria		
Pseudomonas veronii	Cd, Zn, Cu	(Coelho et al. 2015)
Pseudomonas putida	Cr (VI)	(Balamurugan et al. 2014)
Bacillus cereus	Cr (VI)	(Coelho et al. 2015)
Bacillus cereus strain XMCr-6	Cr (VI)	(Dong et al. 2013)
Bacillus subtilis	Cr (VI)	(Balamurugan et al. 2014)
Enterobacter cloacae B2-DHA	Cr (VI)	(Rahman et al. 2015)
Kocuria flava	Cu	(Coelho et al. 2015)
Sporosarcina ginsengisoli	As (III)	(Coelho et al. 2015)
B. Fungi		
Gloeophyllum sepiarium	Cr (VI)	(Achal et al. 2011)
Rhizopus oryzae (MPRO)	Cr (VI)	(Sukumar 2010)
Aspergillus fumigatus	Pb	(Kumar Ramasamy et al. 2011)
Aspergillus versicolor	Ni, Cu	(Taştan et al. 2010)
C. Algae		
Hydrodictyon, *Oedogonium*, and *Rhizoclonium* spp.	As	(Srivastava and Dwivedi 2015)
Spirogyra spp. and *Cladophora* spp.	Pb (II), Cu (II)	(Lee and Chang 2011)
Spirogyra spp. and *Spirulina* spp.	Cr Cu, Fe, Mn, Zn	(Mane and Bhosle 2012)
D. Yeast		
Saccharomyces cerevisiae	Pb, Cd	(Lívia and Benedito 2015)

rhamnolipid, and sophorolipid were also tested for HM (Cu and Zn) removal by Mulligan et al. (2001).

11.4.1.1.4 Algae Remediation Capacity of Heavy Metal

In comparison to other microbial bioabsorbents, algae are autotrophic, meaning they consume few nutrients and produce a large amount of biomass. These bioabsorbents have also been utilized to remove HMs from the environment due to their high sorption ability (Abbas et al. 2014). Adsorption or integration of algae biomass into cells is employed for bioremediation of HM-polluted wastewater. Phycoremediation is employing several forms of algae and cyanobacteria to remove or degrade toxicants to remediate HMs (Chabukdhara et al. 2017). Algae include chemical moieties on their surface that act as metal-binding sites, including hydroxyl, carboxyl, phosphate, and amide (Abbas et al. 2014). Dead *Chlorella vulgaris* cells were utilized by Hussian and Napiórkowska-Krzebietke et al. to remove Cd^{2+}, Cu^{2+}, and Pb^{2+} ions from aqueous solutions under various pH, bioabsorbent dosage, and contact time conditions. These findings demonstrate that the biomass of *C. vulgaris* is an exceptionally efficient bioabsorbent for the removal of Cd^{2+}, Cu^{2+}, and Pb^{2+} at 95.5%, 97.7%, and 99.4%, respectively, from a mixed solution containing 50 mg/dm^3 of each metal ion (Goher et al. 2016).

11.4.1.2 Heavy Metal Removal Using Biofilm

In many experiments, biofilms were utilized to remove HMs. Biofilm is a type of bioremediation that also serves as a biological stabilizer. Biofilms have an extremely high tolerance for hazardous inorganic elements, even at deadly doses. According to research on *Rhodotorula mucilaginosa*, metal elimination efficacy varied from 4.79 to 10.25% for planktonic cells and from 91.71 to 95.39% for biofilm cells (Goher et al. 2016). Biosorbents or exopolymeric substances present in biofilms that contain molecules with a surfactant or emulsifying qualities might be used in biofilm bioremediation approaches (El-Masry et al. 2004).

11.4.1.2.1 Metal-Microbe Interaction

The bacterial cell takes up the heavy metal by different methods, either active transport, ion exchange, electrostatic interaction, complexation, or the production of extracellular polysaccharides (Srivastava et al. 2017) (Fig. 11.4).

When microbes interact with heavy metals, they accumulate in the microbial cell and can be detoxified by mechanisms such as bioadsorption, biomineralization, biodegradation, bioleaching, biotransformation, and bioaccumulation.

11.4.1.3 Methods for Heavy Metal Remediation Using Microorganisms

11.4.1.3.1 Biosorption

Although the terms bioaccumulation and biosorption are often used interchangeably, they differ in how pollutants are sequestered. Biosorption, according to Volesky, is the adsorption of chemicals from solution by biological materials via

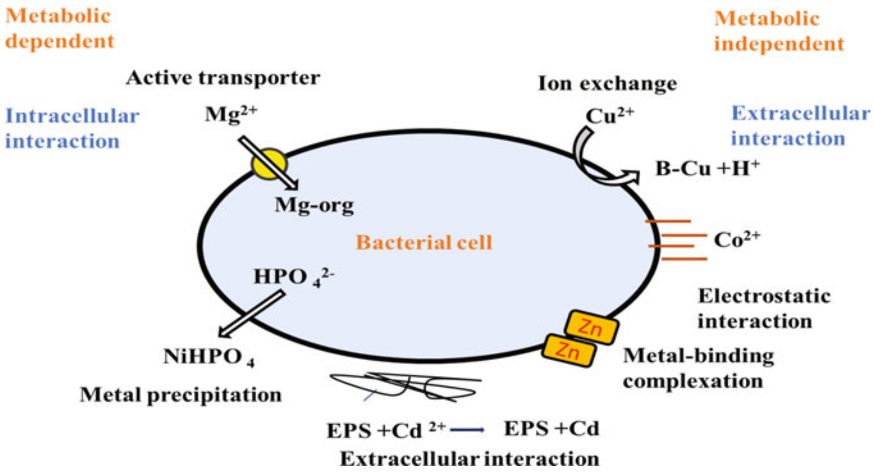

Fig. 11.4 Metal-microbe interaction

physiochemical absorption pathways such as electrostatic forces and ion/proton displacement (Volesky and Holan 1995). Biosorption has been proven to remove a wide range of HMs from aqueous solutions, including very hazardous metal ions such as Cd, Cr, Pb, Hg, and As (Saba et al. 2019). As a result, the diversity of cell wall architectures is critical to biosorption success. By using bioabsorbents like microorganisms (both live and dead), agricultural waste, and other industrial wastes, biosorption can remove pollutants and build the framework for long-term metal removal and recovery (Inoue et al. 2017). Numerous parameters such as pH, temperature, shaking speed, initial pollutant concentration, and bioabsorbent amount are considered to improve biosorption effectiveness. The chemical composition of each contaminant, biomass size, interaction between distinct metallic ions, and ionic strength influence the binding mechanism. Biosorption is also appealing because of a variety of benefits, including low operating costs due to its reversible process, no increase in chemical oxygen demand (COD), ease of desorption, and high adsorption rate. However, other factors must be considered, such as the potential toxicity of pollutants to bacterial cells if living cells are used in this procedure.

11.4.1.3.2 Bioaccumulation Process

Bioaccumulation, on the other hand, is a natural active metabolic process in which HMs accumulate and are taken up by proteins into intracellular living bacterial cells. The initial stage is the adsorption of HMs onto cells, and the metal species are then carried inside the cells, where the HMs can be sequestered by proteins, the lipid bilayer as an import system, and peptide ligands as a storage system (Mishra and Malik 2013). Metal ions were uptake by numerous substances inside the cell cytoplasm to create big ions in intracellular sequestration. Gram-negative bacteria enhanced absorption from the periplasm into the cytoplasm is dependent on the expression of inner membrane importers in extracellular sequestration (Saier 2016; Diep et al. 2018).

11.4.1.3.3 Biomineralization

Biomineralization is the process by which microorganisms mediate and catalyze inorganic reactions to form new mineral assemblages. Therefore, some microorganisms produce certain extracellular polymeric substances (EPSs) or biosurfactant in the extracellular environment, or sometimes they will also produce it in the intracellularly environment which will help to convert the heavy metal into the minerals, a process called biomineralization. Various bacteria like *Bacillus*, *Streptococcus*, etc. help in the biomineralization process (Arnold et al. 2021).

11.4.1.3.4 Bioleaching for Bioremediation

"The dissolving of metals from their mineral source using specific naturally existing microbes" or "the use of microbes to alter metal elements so that the elements can be recovered when water is filtered through it" are two definitions of bioleaching (Mishra et al. 2005). Ni, Cu, Zn, Co, Au, Pb, and As have all been dissolved with it. This process is useful for extracting valuable metal compounds from solid substrates and detoxifying HM-contaminated wastes such as ores, energy, or landfill space as a technology (Singh and Li 2015). However, an investigation has demonstrated that chemolithotrophic techniques cannot handle industrial waste materials containing substantial levels of important metals (Sajjad et al. 2019). Additionally, this is dependent on the metal compounds in the waste as vanadium, chromium, copper, and zinc may all be fully recovered (Blaise et al. 2010). *Thiobacilli* have also been able to detoxify HM-contaminated sewage sludge, soil, sediment, and water (Blaise et al. 2010). From bacteria to fungi and algae, many microorganisms have been isolated from mining and environmental bioleaching settings. *Rhodotorula* sp., *Trichosporon* sp. (yeasts), *Acidithiobacillus* sp. (Bacteria), *Eutrepia* sp. (flagellates), protozoa, and amoebas have all been isolated from a copper mine. Some thermophilic bacteria (particularly *Sulfolobus* sp.) have also been isolated and enhanced from bioleaching environments.

Researchers can examine the particular processes that sustain microbial successions and the impact of community structure on the environment in bioleaching heaps used for copper removal (Wang et al. 2020). Advances in DNA sequencing technology have made it possible to gather unprecedented amounts of information on the genomes of bioleaching bacteria, allowing for the development of metabolic potential estimation techniques and environmental level interactions.

11.4.1.4 Phytoremediation

The use of plants to clean up HMs in the soil is defined as phytoremediation. These include phytoaccumulation, phytostabilization, and phytodegradation (Fig.11.5). The hyperaccumulating plant will take up the heavy metal that will get accumulated

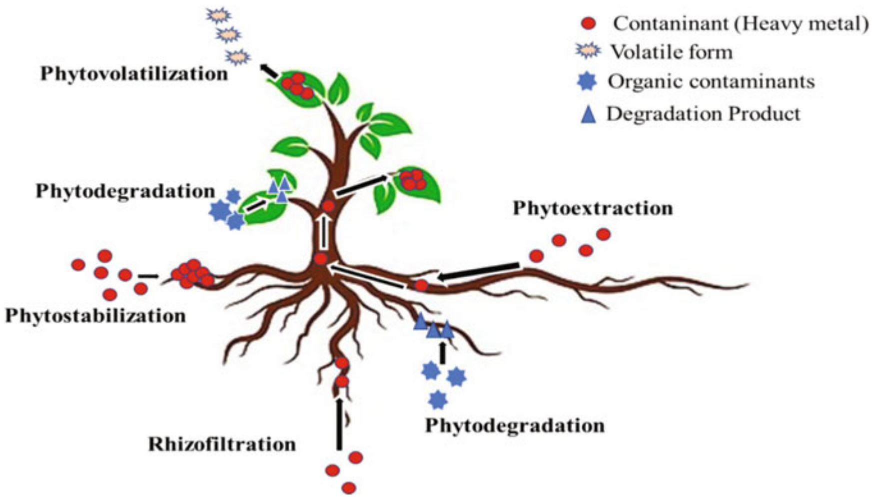

Fig. 11.5 Plants use a variety of phytoremediation techniques

Table 11.2 Microorganisms used in heavy metal remediation of contaminated sites

Family	Species	Heavy metals	References
Brassicaceae	*Arabidopsis halleri*	Cd, Zn	(Zhang et al. 2017)
Brassicaceae	*Alyssum bertolonii*	Ni	(Mengoni et al. 2012)
Brassicaceae	*Arabidopsis halleri*	Cd	(Claire-Lise and Nathalie 2012)
Brassicaceae	*Alyssum murale*	Ni	(Broadhurst and Chaney 2016)
Asteraceae	*Helianthus annuus*	Zn, Pb, Cd	(Fulekar 2016)
Asteraceae	*Berkheya coddii*	Ni	(Slatter 1998)
Caryophyllaceae	*Minuartia verna*	Pb, Zn, Cd,	(Bothe 2011)
Poaceae	*Spartina argentinensis*	Cr	(Nalla et al. 2012)
Pteridaceae	*Pteris vittata*	As	(Rathinasabapathi 2011)
Pteridaceae	*Pteris vittata*	Hg	(Su et al. 2008)
Euphorbiaceae	*Euphorbia cheiradenia*	Cu, Fe, Pb, Zn	(Nematian and Kazemeini 2013)
Fabaceae	*Astragalus racemosus*	Se	(Alford et al. 2012)
Fabaceae	*Medicago sativa*	Pb	(Chibuike and Obiora 2014)
Crassulaceae	*Sedum alfredii*	Pb	(Chen et al. 2012)
Violaceae	*Viola boashanensis*	Pb, Zn, Cd	(Zhuang et al. 2005)

within the plant (Marques et al. 2009; Muthusaravanan et al. 2018; Chaney and Baklanov 2017) (Table 11.2).

In this case, plants will take it up, and sometimes, phytodegradation or the breakdown, phytostabilization, and rhizosphere degradation, that is, degrading of metal in the rhizosphere will happen.

11.5 Conclusion

HM pollution is a serious environmental problem that occurs due to a variety of human activities and has a significant impact on humans and the environment. Because of the biotechnological potential of microbes in removing or recovering metals, our focus has shifted to eco-friendly treatments such as phytoremediation and microbial remediation, which entail HM absorption by microorganisms. Apart from their contributions, biosorbents are potentially beneficial and readily available for removing HMs and for protecting nature and the environment using a bioremediation process. Although just a few studies have been done on this subject, bacteria are one of the most significant microbiological approaches for bioremediation. As heavy-metal pollution alleviators, more research is needed to get the most out of bacterial systems and to determine the specific and unambiguous mechanisms involved in HMs removal by bacteria, fungus, and algae. For the betterment of our environment, we need environmentally friendly remediation solutions based on plants and microorganisms that are viable alternatives to physical and chemical removal methods.

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