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Review Article

REMEDIATION TECHNIQUES FOR HEAVY METAL CONTAMINATED ECOSYSTEM – A REVIEW

M. Madhuppriya*[1], R. Shyamala Gowri[1], A. Saranya[1], P. Rajarajeswari[1], P. Prabhavathi[1], S. Dinesh Kumar[2]

[1]*Department of Microbiology and Biochemistry, Nadar Saraswathi College of Arts & Science, Theni, Tamil Nadu, India*
[2]*Marine Planktonology & Aquaculture Lab., Department of Marine Science, School of Marine Sciences, Bharathidasan University, Tiruchirappalli, Tamil Nadu, India*
Corresponding author: shyamalagowri15@gmail.com

ABSTRACT
Universal rejuvenation is responsible for industrialization, urbanization and numerous anthropogenic activities, which involves the vast application of heavy metals. Mostly heavy metals are released to our environment during the processing and disposal of heavy metal containing products. Environmental pollution caused by the heavy metal increases attention worldwide because of their toxicity in plant, animal and human beings and their lack of biodegradability. Once metals are contaminating the environment, they may persist for long time depending on the nature of metal. The remediation process for heavy metal contaminated sites may be in-situ or ex-situ, On-site or off-site and biological, physical and chemical. Also these techniques used in combination with each other for more economical and efficient remediation of a heavy metal contaminated ecosystem. Biological remediation in biotransformation of heavy metals into non-hazardous form is well-documented, and considerate the molecular mechanism of metal accumulation has frequent biotechnological implications for bioremediation of metal-contaminated sites. In view of this, the present review investigates the several remediation technologies used for the recovery of metal-contaminated environments.

Keywords: Heavy Metals, Anthropogenic Activities, Pollution, Toxicity, Remediation Techniques

1. INTRODUCTION
For ensuring a functional and balanced ecosystem, environmental protection is an important factor. With the rapid expansion of many industries, wastes comprising heavy metals are unswervingly discharged into the environment, which has led to the accumulation of heavy metals and exaggeration of toxicants in the food chain. Living organisms necessitate trace amounts of some heavy metals such as cobalt, copper, iron, manganese, molybdenum and vanadium. But the indiscriminate release of heavy metals cause deleterious health effects on human life and aquatic biota. Because the toxic heavy metals cannot be broken down to non-toxic forms and therefore has long-lasting effects on the ecosystem. Due to the prolonged exposure and higher accumulation, some of the heavy metals are not only cytotoxic but also carcinogenic and mutagenic in nature. Such as arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, zinc etc. are toxic even at very low concentrations [1]. However the increasing concentration of several metals in soil and water due to industrialization has created an alarming situation for ecosystem. Therefore several management practices are being applied to reduce level of metal contamination in soil and finally to the food chain.

2. HEAVY METALS
Heavy metals are chemically defined as the class of a distinct subdivision of elements characterized with metallic properties. Transition metals, certain lanthanides, metalloids and actinides encompass heavy metals. The various features of heavy metal include a density range of 3.5-7 g/cm^3,atomic weight ranging from 22.98 to <40, and atomic number of <2 [2]. In nature, totally 92 elements exist and about 30 of these are metalloids. The elements Be, B, Li, Al, Ti, V, Cr, Mn, Co, Ni, Cu, As, Se, Sr, Mo, Pd, Ag, Cd, Sn, Sb, Te, Cs, Ba, W, Pt, Au, Hg, Pb and Bi may especially affect environmental quality and human health [3]. Trace amounts of some heavy metals including cobalt, copper, iron, manganese, molybdenum and vanadium are essential to living organisms. But the extreme levels of heavy metals lead to severe threat to environment superiority and life of both plants and animals, counting

serious diseases in humans. According to United States Environmental Protection Agency (UEPA), heavy metals are listed as priority pollutants. In the level of toxicity lead, mercury, arsenic and cadmium are ranked first, second, third and sixth respectively, listed by US Agency for Toxic substances and Disease Registry (ATSDR).Generally all hazards present in toxic waste sites on the basis of their prevalence and severity of toxicity are listed by US Agency for Toxic substances and Disease Registry. The issue of heavy metal pollution is very much concerned because of their toxicity for plant, animal and human beings and their lack of biodegradability. In the current scenario, the levels of heavy metals released by the anthropogenic activities exceed the natural level of heavy metals present in the ecosystem.

3. HEAVY METAL DISTRIBUTION

In some developing countries where heavy metal remedial techniques are nascent, the natural resources, chiefly soil and water contaminated by the accumulation of toxic heavy metals. Because of their potential long-term effects can easily enter into food chain and also cause risk for humans, animals, plants and whole environment [4].Soil is the major repository of heavy metal contaminants in terrestrial ecosystem. Also, in aquatic systems, the sediment serves as the ultimate sink for the heavy metals. The geogonic or anthropogenic activities are the major source for the origin of heavy metals to the natural environment, which cause adverse effects on biological ecosystem. The major environmental contamination sources include mining wastes, land fill leachates, municipal waste waters, urban runoffs and industrial waste waters, particularly from the electroplating, electronic and metal-finishing industries. Additionally, heavy metals are used in electronics, machines and the artifacts of daily life; high technology applications are also extensive [5]. Such usage of heavy metals in our modern society results in the deterioration of environment due to improper waste disposal.

4. SOURCES OF HEAVY METALS AS CONTAMINANTS IN SOIL

In our ecosystem, the metal contaminated soil effects can be malignant, especially on soil microbial properties [6] and soil diversity with respect to taxonomy and functionality [7]. Also some natural processes, such as land erosion, chemical weathering of minerals and volcanic-associated activities significantly contribute metals to soil and cause severe effects. Through the diverse human socioeconomic and development activities, include mining, fuel and energy generation, waste water disposal and treatment large amount of heavy metal induced environmental deterioration. Such pollution can be due to various activities geared toward industrialization; hence the pollutants arise from waste disposal, lead-induced gasoline and paints, petrochemical spills, residues from incomplete combustion of coal [8, 9].

5. SOURCES OF HEAVY METALS AS CONTAMINANTS IN AIR

Atmospheric contamination by heavy metals may be from a variety of sources, but majorly two sources such as transportation sources and stationary sources deposit heavy metals to the atmosphere. Transportation sources such as when items are carried with trucks and buses. Stationary sources of heavy metals include factories, refineries and power plants. Other sources may include indoor sources, which known as construction materials and cleaning solvents and volcanic associated activities, which are classified as natural sources. Due to the urban industrialization of copper plants, sulphuric acid plants, paint factories and the waste from mining and chemical industries cause the lead pollution. By the wind pollution the heavy metal contaminants transported from the industrial waste to the surrounding environment.

6. SOURCES OF HEAVY METALS AS CONTAMINANTS IN WATER

Untreated sewage and other waste water types from chemical industries and urban mining is the ultimate source for heavy metals which contaminate the water source severely in the ecosystem. Some activities such as mining and construction also add high level of heavy metal concentrations to water sources, especially ground water. Previously some mature fruit orchard was used as a pesticide, which may contain high levels of arsenic. At extreme levels, these metals pose several health risks. For maintaining the ecological equilibrium, lake waters and other forms of surface water naturally contain some concentrations of heavy metals at appreciable levels. Unfortunately, some anthropogenic activities causing pollution change this ecological equilibrium leading to incessant contamination of ground water caused by the toxic heavy metals. At small concentrations pollutants may permeate gradually to the ecosystem. But threatening effects may be amplified due to bioavailability and accumulation with the entry of the pollutants into the food chain. Hence, the global distribution of metal pollution should be elucidated to show the need for reclamation in the environment.

7. IMPACTS OF HEAVY METALS

7.1. Impacts on The Soil

Due to its various anthropogenic activities, soil is the major sink of heavy metals. Majorly the composition and activity of soil microbial communities may be altered by heavy metals. Extreme level of heavy metals in the soil results in high soil toxicity .Compared with the non-contaminated soil the enzyme activity is reduced (10-5 times) in the heavy metal contaminated soil [10]. Examples for some common heavy metals include Pb, As, Cr, Ni, Zn, Cd, Cu and Hg [11]. Mostly the heavy metals may persist in soil for a long time .Heavy metals induce threatening effects on soil microbes and the level of impact varies due to physiochemical conditions, such as pH, temperature, clay minerals, abundance of organic matters, inorganic anions and cations and chemical forms of the metal [12]. They also reduce organic matter decomposition and nutrient recycling in the soil.

7.2. Impacts on Plants

Biological and physiological processes that are crucial to plant growth are majorly interfered by toxic heavy metals. A heavy metal contaminated plant may exhibit reduced yield production, which consequently affects the food chain. Due to oxidative stress, cytoplasmic enzyme inhibition and cell structure damage occur in the heavy metal contaminated plant [13]. An example of an indirect toxic effect by the heavy metal is the replacement of essential nutrients at the cation exchange sites of plants. For example, Under Pb toxicity, the water content of *Brassica juncea* plants remarkably decreases, although this species is considered as tolerant to the heavy metals [14]. Plants exhibit stunted growth, deformation, reduced physicochemical activities and overall alteration of cellular metabolism when they exposed to heavy metals [15]. Also heavy metals affect the growth and photosynthetic pigments of plants. The most toxic metals which include Hg, As, Pb, Cd and Cr display considerable public health significance.

Table 1: Effect of heavy metals on plants and human health [16]

Heavy metal	Effect on plants	Effect on human health
Cr	Reduces the rate of photosynthesis and enzyme activity, reimbursement the plant membrane and roots and causes chlorosis.	Causes hair loss
Cd	Decreases seed germination, lipid substance and plant growth.	Carcinogenic, mutagenic, endocrine disruptor, causes lung damage and bone fragility, affects calcium regulation in biological systems
Cu	Affects growth, reproductive processes and photosynthetic of plants and decreases the thylakoid surface area.	Causes brain and kidney damage, liver cirrhosis, chronic anaemia, stomach irritations
Hg	Decreases photosynthetic activity, water uptake and antioxidant enzymes.	Causes autoimmune diseases, depression, fatigue, hair loss, insomnia, memory loss, vision disturbance, brain damage and kidney failures.
Ni	Reduces seed germination and synthesis of protein, chlorophyll and enzyme.	Causes skin allergies, such as itching; cancer of lungs, nose, sinuses and throat through continuous inhalation; immunotoxic; neurotoxic; genotoxic.
Pb	Reduces chlorophyll production and affects plant growth.	Reduced intelligence, short-term co-ordination problems and risk of cardiovascular disease.
Zn	Reduces seed germination.	Causes dizziness and fatigue

7.3. Impacts on Human Health

Some types of heavy metals are required by living organisms at certain amounts, but excessive levels are considerably carcinogenic or toxic to human health [16]. The highest toxicity elements are typically Arsenic (As), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Manganese (Mn) and Nickel (Ni) [17]. Humans need Co, Cu, Cr, Mn and Ni in trace amounts. Nonetheless, other heavy metals cause severe effects or illness. Some heavy metals generate the bio toxic compounds in the human body by interact with the bio molecules that are remarkably stable with a low dissociating ability [18]. Mn, Hg, Pb and As can interfere with the central nervous system. Similarly Hg, Pb, Cd and Cu cause severe problems to the excretory organs, especially kidneys, whereas bone or teeth formation is susceptible to the effects of Ni, Cd, Cu and Cr. Through water consumption and food chain, humans are commonly exposed to toxic heavy metals and also through high ambient air concentrations near emission sources. In the food chain, generally toxicity occurs in the following order: Soil > plant > animal > human.

8. REMEDIATION OF HEAVY METAL - CONTAMINATION

Once metals are contaminating the environment, they may persist for long time depending on the nature of metal. The remediation process for heavy metal contaminated sites may be in-situ or ex-situ, on-site or off-site and biological, physical and chemical. Also these techniques are used in combination with each other for more economical and efficient remediation of a heavy metal contaminated ecosystem.

9. PHYSICAL REMEDIATION

9.1. Soil Replacement

Replacing or partially replacing of contaminated soil by non-contaminated soil known as the soil replacement technique. Before 1984, excavation, off-site disposal and soil replacement were the most common technique for cleaning up heavy metal contaminated sites. Through the soil replacement technique, the concentration of heavy metals in soil may dilute and in turns increases soil functionality [19]. The replaced soil is generally treated to remove heavy metals or in some cases dumped in other places. Soil replacement may be carried out by 1) Soil spading and 2) New soil importing. After soil replacement process, cultivation of vegetables indicated a clear improvement of vegetables and soil quality [20]. The contaminated soil and ecosystem effectively isolated by the soil replacement technique, therefore minimizing its effect on the environment. Due to high labour work, this technique is costly and is appropriate for heavily contaminated soils with small area. Distance transport of excavated soil may be cost effective. Due to the risk of loss of soil fertility, this technique may not be applicable to agriculture fields.

9.2. Soil Isolation

Separation of heavy metal contaminated soil from the uncontaminated soil known as soil isolation, but for complete remediation it still needs other auxiliary engineering measures. To prevent off-site movement of heavy metals and other contaminants, isolation technologies are used by restricting them within a specified area [21]. And it is also used to avoid further contamination of ground water by heavy metals. But other remediation methods are not economically or physically feasible. For separation of contaminated water and soil by restricting the flow of ground and/or surface water at a contaminated site, subsurface barriers are used. Some of the materials which are used for subsurface barriers are sheet piles, grout curtains and slurry walls.

9.3. Vitrification

By applying high temperature treatment at the contaminated site, the mobility of heavy metals inside soil can be reduced that leads to the formation of vitreous materials. During vitrification process, some metal species (such as Hg) may be volatilized under high temperature that must be collected for further disposal. Vitrification process is majorly applied to soils contaminated with inorganic and organic contaminants. For example, Dellisanti [22] carried out an in-field Joule heating vitrification of tons of Zn and Pb rich ceramic waste by heating up to about 1850ºC. They concluded that the vitrification method was greatly efficient to clean up tons of heavy metal contaminated waste materials. During vitrification temperature plays an important role in the immobilization of heavy metals in soil samples. For example, Navarro *et al.*,[23] carried out vitrification of waste from Ag-Pb mines using solar technology. They concluded that vitrification caused immobilization of Zn, Mn, Fe, Cu and Ni at 1350ºC, whereas Zn, Ni, Mn and Cu were mobilized at 1050ºC. In both in-situ and ex-situ method the vitrification process can be performed. Due to the low cost and energy requirements, in-situ method is preferred. *Ex-situ* vitrification processes include various stages such as excavation, mixing, pre-treatment, melting feeding and casting of the melted products [22]. Ex-situ vitrification method is costlier than in-situ vitrification method because it requires high energy for melting. The vitrified material can be recycled and used as reusable materials, aggregate and clean fill. Under field conditions or at large scale, this technique can be highly expensive. Therefore, this technique can be applied only for small scale remediation of heavy metal polluted sites.

9.4. Electro Kinetic Remediation

A new and cost effective physical method for the remediation of heavy metal is soil electro kinetic remediation. It works based on the principle that the electric field gradient of suitable intensity is established on two sides of the electrolytic tank containing saturated contaminated soil. Majorly heavy metals present in the soil are separated via electrophoresis, electric seepage or electro migration and thus decrease the contamination [19]. It is also in combination with other techniques such as electro kinetic microbe joint remediation, electro kinetic-chemical joint remediation, electro kinetic-oxidation/reduction joint remediation, coupled electro kinetic phytoremediation, electro kinetics coupled with electro spun polyacrylonitrile nanofiber membrane , and electrokinetic remediation conjugated with permeable reactive barrier. The heavy metals which having poor conductivity such as sulphides or present in metallic form such as Hg removal process requires preliminary dissolution. In such cases the removal efficiency of electrokinetic remediation method may increase by use of an appropriate electrolyte which includes distilled water, organic acids or synthetic chelates. It is easy to install and operate. So this method is economically effective. Also this method does not abolish the nature of the soil [24].

10. CHEMICAL REMEDIATION

10.1. Immobilization Technique

Decrease of metal mobility, bioavailability and bio accessibility of heavy metals in the contaminated sites by adding immobilizing agents known as immobilization by complexation, precipitation and adsorption reactions heavy metals can be immobilized in soil. These techniques cause redistribution of heavy metals from soil solution to solid particles thus restraining their transport and bio availability in soil. Generally, heavy metals immobilization is carried out by using organic and inorganic amendment to soils. Most commonly amendments include cement, clay, zeolites, phosphates, minerals, microbes and organic amendments [25]. For the immobilization of heavy metals in contaminated soil, low cost industrial residues such as termitaria, industrial eggshell and red mud [26] are widely used. In modern years, biomaterials have been significantly used to immobilize heavy metals in soil due to their easy availability and squat cost. Among variety of biomaterials, the use of biochar has received considerable attention to immobilize heavy metals in soil. Several researches revealed that addition of biochars to soil greatly enhanced the sorption of heavy metals and significantly reduced their mobility and phytoavailability [27].

10.2. Encapsulation

Immobilization of toxic metal solutions is an effective method to reduce hazardous material and their subsequent safe disposal as a landfill by encapsulating them in manageable solid blocks [28]. Encapsulation technique involves the mixing of the contaminated soils with other products, such as concrete, lime or asphalt. Thus the contamination of surrounding materials is prevented by immobilization of contaminated soil. Because of its easy availability, versality and cost effectiveness, cement is preferred for the best binding materials which are used in solid blocks formation [29].

10.3. Soil Washing

By using various reagents and extractants heavy metals are majorly removed from soil, this process is known as soil washing [30]. The extractants can leach the heavy metals from the soil. Currently, the usage of suitable extractants or reagents for leaching heavy metals from contaminated soils is considered as an alternative to some of the conventional techniques. In this soil washing technique, depending on the type of metal and soil, suitable extractant solution is mixed with the contaminated soil. The heavy metals in soil are transferred from soil to liquid phase, and then separated the leachate by the precipitations, ions exchange, chelation or adsorption process [31]. The separated soil that fulfils regulatory criteria may be backfilled to the original site. Due to the complete removal of heavy metals from soil, soil washing technique is frequently used for the recombination of heavy metal contaminated sites.

11. BIOLOGICAL REMEDIATION

To rectify and re-establish the natural condition of soil, Bioremediation is one of the most viable options. In bioremediation technique, removal or detoxification of heavy metals from the contaminated sites is accomplished by plants/microorganisms. Due to its cost-effective and non-invasive it is the most considerable option for removal of toxic heavy metals. And it also provides a permanent solution.

11.1. Phytoremediation

Use of plants to remediate and revegetate the heavy metal contaminated sites known as phytoremediation. This technique is also known as botano remediation, vegetative remediation, green remediation and agro remediation. For removing the heavy metals from the contaminated sites, phytoremediation technique utilizes a variety of plant processes and the physical characteristics of plants. In recent years, some special emphasis has been developed on phytoremediation. Since this property can be exploited for remediation of heavy metal polluted soils.It is one of the most cost effective, efficient and eco-friendly in-situ remediation technologies which is driven by solar energy. Also the exposure of polluted substrates to humans, wildlife and the environment is prevented by this remediation technology. Phytotransformation (An incomplete or absolute breakdown/degradation of complex organic molecules with in plant tissues), Phytostimulation (A circumstance that allows the seepage of plant enzymes or secretion into the root zones to induce or enhance the metabolic activities of relevant microbes for the breakdown of organic pollutants), Phytostabilization (The choice that utilizes plants to diminish or restrict the movement of pollutants of interest. This process is achieved by using plants as barriers to erosion, leaching or other runoffs as a way of mitigating bioavailability of the pollutants within the environment. Thus pollutant entry into ground water or food chain is considerably minimized), Phytovolatilization (This process is the volatalization of pollutants or metabolites using plants. Most pollutants, especially the volatile organic carbons are removed via this process. And also selenium & mercury are removed with this technology) are the diverse groups of phytoremediation techniques [32]. Due to its efficacy and cost efficiency removal of heavy metals through phytoremediation, especially hyper accumulators to degrade and detoxify contaminants has received wide attention .Compared to other plants, hyper accumulators have been found to exhibit higher heavy metal tolerance and accumulating abilities [33].

11.2. Microbial Bioremediation

Microorganisms are omnipresent in nature that lead in heavy-metal contaminated soil and can easily transfer the heavy metals into non-toxic forms. Microorganisms mineralize the crude contaminants to carbondioxide and water or to metabolic intermediates which are mainly pertinent as primary substrates for cell growth Microorganisms have two-way defence. Such as degradation of target pollutants by producing degradative enzymes as well as make the resistant to relevant heavy metals. Under the metal stress, the survival of microbes involves several mechanisms, which known as the efflux of metal ions outside the cell, accumulation and development of complex metal ions inside the cell, and eventual decrease of the toxic metal to non-toxic form. The various microorganisms involved in this process known as bacteria, fungi, yeast and algae. Potent metal-tolerant bacteria include *Bacillus sp., Pseudomonas sp., Streptomyces sp*. [34]. Due to the high percentage of cell wall material and excellent binding capacity, fungus biomasses are effective among various microorganisms. Some of the examples for fungi/yeast which have high levels of biosorption potential are *Aspergillus sp., Streptoverticullum sp.,* and *Saccharomyces sp.* [35]. Several approaches are used in the microbial remediation to remove toxic heavy metals from the contaminated sites. Such as bioaugmentation, biostimulation and bioattenuation.

11.3. Bioaugmentation

In bioaugmentation technique the heavy metal contaminated sites are remediated by introducing specific potential microbes or groups of microorganisms. Many abiotic and biotic factors may influence the efficiency of the bioaugmentation method [36]. In bioaugmentation technique the indigenous bacterial species are used to accelerate the removal of undesirable compounds in contaminated sites.

11.4. Biostimulation

Biostimulation is the major technique where the environment is modified to stimulate the existing bacteria, which can enhance bioremediation. This technique can be carried out by adding some essential nutrients, such as phosphorus, nitrogen, oxygen or carbon. By adding these essential nutrients the population or activity of naturally occurring microorganisms may increased. Due to adaptation to the subsurface environment and optimal spatial distribution within the subsurface the native microbes present in soil induce bioremediation is the major advantage of the biostimulation technique. Some factors such as nutrients, pH, temperature, moisture, oxygen, soil properties and contaminant type may limit the activity of biostimulation in soil for heavy metal degradation [37].

11.5. Bioattenuation

In microbial remediation of heavy metals bioattenuation is another in-situ treatment. By utilizing natural processes this technique control the spread of contamination from chemical spills and decrease the concentration of pollutants at contaminated sites. Due to the types of pollutants and associated physical, chemical and biological characteristics of the soil and ground water the rate of bioattenuation may vary. To remediate contamination problems this technique is an effective, inexpensive and the most appropriate method. Bioattenuation dissipate the contaminants through biological transformation.

Table: 2 List of selected plants & microorganisms reported for bioremediation of heavy metals

Heavy metal	Plant species	Degrading Microorganisms	Reference
Cd	*Salix spp. (Salix viminalis, Salix fragilis)*	*Alcaligenes sp, Pseudomonas sp*	[38, 39]
Cu	*Populus spp. (Populus deltoids, Populus nigra)*	*Cardidatropicalis, Bacillus licheniformisc*	[40, 41]
Pb	*Corn (Zea mays)*	*Penicillium chrysogenum*	[42, 43]
Ni	*Jatropha (Jatropha curcas)*	*Bacillus subtilis, P.licheniformis*	[44, 45]
Zn	*Populus canescens*	*Rhizopus arrhizus,* *Penicillium spinulosum*	[46, 47]
Hg	*Populus deltoids*	*Penicillium chrysogenum*	[48, 49]

12. GENETIC ENGINEERING IN BIOREMEDIATION PROCESS

Genetically engineered microorganisms (GEM) are organisms whose heritable material has been altered by means of recombinant DNA technology to generate a character specific well organized strain for bioremediation of soil, water and activated sludge by exhibiting enhanced degrading capabilities against a wide range of chemical contaminants [50]. It offers the advantage of constructing microbial strains which can withstand adverse stressful situations and can be used as a bioremediators below diverse and complex environmental conditions. Genetic engineering of endophytes and rhizospheric bacteria for plant-associated humiliation of pollutant in soil is measured to be one of the most promising new technologies for remediation of metal contaminated sites [51]. Bacteria like *Escherichia coli* and *Moreaxella sp.* Expressing phytochelatin 20 on the cell surface have been shown to accumulate 25 times more Cd or Hg than the wild-type strains [52].Sustaining the recombinant bacterial population in soil, with various environmental conditions and competition from native bacterial population in soil is the major obstacle for utilizing these genetically engineered microbes in hostile field conditions [53].

Table 3: List of selected genetically engineered bacteria for remediation of heavy metals

Heavy Metal	Genetically engineered bacteria	Expressed gene	Reference
As	*E.coli* strain	Metalloregulatory protein ArsR	[54]
Cr	*P.Putida* strain	Chromate reductase (ChrR)	[55]
Hg	*E.coli* JM109	Hg^{2+} transporter	[56]
Ni	*P.fluorescens* 4F39	Phytochelatin synthase (PCS)	[57]
Cd^{2+},Hg	*Ralstonia eutropha* CH34, *Deinococcus radiodurans*	merA	[58]
Hg	*Achromobacter* sp AO22	mer	[59]

13. CONCLUSION

Although the heavy metals are natural constituents of the environment, its indiscriminate use for human purposes has altered their geochemical cycles. This results in excess release of heavy metals into natural resources like the soil and aquatic environments. Prolonged exposure of heavy metals can have deleterious health effects on human life. Increasing public awareness of environmental pollution influences search and development of technologies that help in cleanup of heavy metal contaminations. In order to reduce the level of metal contamination, several remediation technologies have been implemented. This review revealed that among all techniques, an alternative and eco-friendly remediation technology should be promoted in the developed and particularly developing countries, where heavy metal contamination is a rigorous problem.

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