American Journal of Biology and Natural Sciences
https://biojournals.us/index.php/AJBNS
ISSN: 2997-7185

The Effectiveness of Bioremediation Using Indigenous Bacteria for the Removal of Heavy Metals from Contaminated Soil

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Received: 2025, 15, Jun
Accepted: 2025, 21, Jul
Published: 2025, 12, Aug

Annotation: The impact of heavy metals on health, flora, fauna, and soil fertility is enormous. Several researchers have focused on the use of various strains of bacteria to assess their potential for bioremediation of heavy metal contaminated soil. Most of them have used non-indigenous bacteria in their study for the bioremediation of heavy metals. Bacteria isolated from heavy metal contaminated soil are expected to show higher tolerance and suitable to be used for the bioremediation of heavy metals. The present review aims at emphasizing the recent developments on the bioremediation of heavy metal contaminated soils using indigenous bacteria.

Keywords: bioremediation, heavy

metal, contaminated soil, bacteria.

1. Introduction

Heavy metal contamination in soil, water, and sediments is a widespread global problem generated by rapid anthropogenic activities [1]. The release of heavy metals into the environment contaminates living and non-living resources and contributes significantly to environmental pollution [2]. Rapid industrialization to meet the burgeoning global population demands has contributed significantly to increased heavy metal concentrations in the environment. Many analytical reports have revealed increasing instances of heavy metal contamination in many developed and developing countries with serious health implications. Microbes can survive in heavy metal-rich environments by evolving resistance, removing metals, and transforming them into non-soluble, non-toxic, and less mobile forms. Microbes that possess resistance to heavy metals remain more stable for bioremediation than non-indigenous microbes. The presence of heavy metal ions results in varied distribution and activities of microbes due to receptor protein preferential attachment with particular shapes towards certain metal ions. It continues to be a serious threat to human health; hence, adequate mitigation is needed to get rid of elevated heavy metal ions from contaminated soil or water. Conventional production methods, e.g. ion exchange, chemical precipitation, and electrodialysis, are time-consuming and expensive. In addition, they are dependent on operating conditions such as pH, temperature, and redox potential, complicating the removal of heavy metal contaminants from contaminated media. [3][4][5]

2. Background on Heavy Metal Contamination

Heavy metals with a density of more than 5 g/cm3 like cadmium (Cd), chromium (Cr), nickel (Ni), arsenic (As), zinc (Zn), copper (Cu) and lead (Pb) mainly found in soil and water [1]. Sources of heavy metals are comparatively divisible in two major types, natural and anthropogenic. Natural sources are the materials which expose naturally by volcanic eruptions and heavy metals transported to the particular structure like soil and water. Anthropogenic sources industrial and domestic discharges are responsible for transport heavy metals. The heavy metals are very dangerous to the environment and human being due to negatively affect our natural resources and habitat of survival. The heavy metal like cadmium (Cd) when it exposed continuously it is poisonous for human being. Nausea, vomiting and irritation in the eye cause due to lead (Pb) with continuous exposure to soil water. Therefore these water and soil are contaminated by heavy metals then the leakage of metals from soil to water is very rapid. Sometimes the contaminant soil and water exposed to bioaccumulation. The bioaccumulation of heavy metals affect human being via food chain and these are responsible for cancer and, damage to brain, kidney and nervous system.

2.1. Sources of Heavy Metal Contamination

The advancements of science and technology over the years have transformed lifestyles, making life easier and more comfortable. However, the drawbacks of this progress have led to environmental contamination. The accumulation of toxic and other harmful wastes in the environment has become one of the biggest drawbacks, imposing serious hazards to both humans and ecological systems, highlighting the urgent need for cleanup strategies [1].

Heavy metals are metals or metalloids with a density greater than 5 g/cm3, such as lead (Pb), copper (Cu), zinc (Zn), chromium (Cr), mercury (Hg), and arsenic (As). Smelting, electroplating, mining, soil pesticides, phosphate fertilizers, tanneries, and sewage sludge combustion activities are important sources of heavy metals. Lead, Hg, Cd, Cr, and As are extremely toxic and non-biodegradable; they cannot be transformed to non-toxic forms. All these metals can enter the food chain and cause severe health problems.

2.2. Health and Environmental Impacts

Heavy metal contamination causes acute and chronic toxicity in many plant and animal species. Once point-source contamination occurs, heavy metals can continuously leach into the environment, thereby endangering the aquatic supplies in nearby areas [1]. The arsenic problem has been thought to affect 35 countries, including India, Mexico, China, and the United States. Nigeria is not excluded either: contamination from tannery, textile, battery, printing, and petroleum industries releases several heavy metals, including arsenic, mercury, iron, cobalt, zinc, and sturdy [2]. Additionally, Pb, Cd, and Cr reached dangerous concentrations near the vicinity of refuse sites and mechanic villages, where repair work for heavy machines also involves oiling vehicles. Maximal effluents discharged within these areas continue to pollute the soils and water bodies around them, threatening the environment and their inhabitants.

Heavy metals in soils change the diversity and functioning of soil microbial communities, affecting ecological balance and soil sustain. Heavy metals may also enter the food chain, leading to a variety of health disorders. Long-term exposure to Pb may cause abdominal pain, headache, anemia, and weakness. Oxidative damage due to radical oxygen species also causes cellular or gene damage. Metals can also impair enzymatic activity, thus affecting DNA repair, blocking the sulfhydryl groups of enzymes, or substitute metals needed for their activity. As essential metals, such as Cu and Zn, may displace other metals in larger quantities, organisms accumulate toxic metal concentrations. [6][7][8]

3. Bioremediation: An Overview

Heavy metals that are immensely toxic, non-degradable, and persistent in contaminated soils are constantly emitted from industrial wastewater, ash disposal, and other tailings. The heavy metals can accumulate in living organisms and cause serious health problems since they are carcinogenic or mutagenic even in very low concentrations. Various physical–chemical processes have been employed for the removal of heavy metals; however, high costs and incomplete removal of heavy metals limit their use for on-site remediation. Other treatments have therefore been focused on biological processes. Bioremediation is a promising technique that employs indigenous bacteria for the effective removal of toxic heavy metals from contaminated soil. Indigenous microorganisms isolated from the heavy-metal-contaminated soil have proven to be more effective at bioremediation than laboratory standard strains or those from other environmental sources. Heavy-metal-contaminated indigenous bacteria are exposed to stresses for long periods and develop various mechanisms that enhance their survival in harsh environments. Several studies demonstrate the potential for bioremediating heavy metals using indigenous bacterial isolates under laboratory, pilot-scale, and field conditions [1].

Bioremediation is the use of living organisms to degrade or transform toxic and hazardous contaminants to less toxic or nontoxic substances. Bioremediation techniques using physical, chemical, and biological approaches have been used for the elimination or reduction of heavy metals. Contamination by heavy metals is a serious environmental threat to all living organisms because they are non-biodegradable by natural processes and pose potential danger for carcinogenic problems under prolonged exposure.

3.1. Definition and Principles

Bioremediation is the process by which indigenous bacterial strains detoxify contaminants or convert them into less harmful forms [1]. Indigenous microorganisms extracted from contaminated soil are highly adapted to the environmental conditions of their native habitat, which leads to enhanced bioremediation performance compared to non-indigenous strains introduced from elsewhere.

The use of indigenous bacteria for bioremediation exploits three primary mechanisms of heavy metal removal—biosorption, bioaccumulation, and biotransformation. Biosorption entails the passive attachment of metal ions to the cell walls of bacterial cells, particularly those of dead or inactivated cells. Bioaccumulation involves the active uptake of metal ions by live bacterial cells through metabolic processes. Biotransformation refers to the enzymatic alteration of metal ions to less toxic or less mobile forms. All three mechanisms—biosorption, bioaccumulation, and biotransformation—have been successfully documented with indigenous bacterial strains. [9][10][11]

3.2. Types of Bioremediation

Bioremediation is a strategy for soil and water remediation that employs biological agents such as plants, microbes, algae, fungi, or their products to detoxify pollutants. The nature of the pollutants and the available resources dictate the choice of bioremediation technique. While many complementary options exist, some methods excel at removing specific classes of pollutants, such as heavy metals.

Bioremediation is categorized into three types: (1) Biostimulation—enhancing the activity of existing microbial communities by modifying environmental conditions or adding nutrients; (2) Bioaugmentation—introducing specialized microbial strains that degrade pollutants into contaminated sites; and (3) Bioventing—injecting air into the soil to stimulate indigenous aerobic organisms to degrade organic contaminants. Designing an effective bioremediation system requires understanding the pollutant's properties, soil characteristics, and site hydrology [1]. The choice and frequency of bioremediation methods ultimately determine the remediation efficiency.

4. Indigenous Bacteria in Bioremediation

Indigenous bacteria are frequently more promising than non-native species for bioremediation of heavy metals. Several strains isolated from mining sites, such as Micrococcus sp., Pseudomonas putida, and Enterobacter sp., efficiently remove heavy metals from both solution and soil. Compared with imported bacteria, indigenous microorganisms tend to be better adapted to the local climate, soil pH, soil moisture content, salt content, and diversity of contaminants [1].

4.1. Characteristics of Indigenous Bacteria

Heavy-metal contamination is one among the natural and anthropogenic environmental problems. This contamination is mainly due to mining, smelting, electroplating, metal dying, paint industries, water runoff from soil erosion, and sediments which can be a threat to human health, plants, and aquatic life [1]. Hence, removing heavy metals from soil is important to prevent associated health hazards. Bioremediation is an environment-friendly technique, an emerging technology emphasizing the use of micro-organisms to treat heavy-metal contamination. Several studies have been conducted to assess the bioremediation capabilities of indigenous bacteria extracted from contaminated soil. Evidence suggests the removal of heavy metals from contaminated soils is more efficient when samples are exposed to indigenous bacterial strains. Indigenous bacterial strains also demonstrate greater resistance to high concentrations of heavy metals than non-indigenous strains, indicating that bioremediation can be optimally achieved with native microbial populations. [12][13][14]

4.2. Advantages of Using Indigenous Bacteria

Indigenous bacteria isolated from contaminated sites consistently demonstrate resistance to environmental stresses and heavy metals and effectively remove heavy metals from soils [1]. Bioremediation exploits these features, leveraging indigenous microorganisms' adaptations for decontamination.

Indigenous microbes are more environmentally compatible than non-native strains, which may struggle to survive or disperse uncontrollably. The use of native populations also ensures that the introduced microbial biomass establishes readily for immediate contaminant degradation rather than engaging in extensive adaptation.

Indigenous bacteria often exhibit a narrower substrate specificity, minimizing interference with native soil chemistry and further enhancing environmental suitability. Their efficiency in removing contaminants from polluted soil highlights the advantages of employing native bacteria for bioremediation.

5. Mechanisms of Heavy Metal Removal

Microorganisms including bacteria and fungi can remove heavy metals from aqueous solutions through mechanisms such as biosorption, bioaccumulation, and biotransformation [1]. The principal mechanism of metal removal from aqueous solution is adsorption by the extracellular polymers. Biosorption is a metabolism-independent process that does not require nutrients, is unaffected by metal toxicity, and can be adapted in industrial systems. It is mediated mainly by complexation, coordination, and ion exchange and occurs mainly by functional groups such as carboxyl, hydroxyl, sulphydryl, amino, phosphate, imidazole, phenol, indole, anhydride, and other unidentified ligands present on the surface of the microbial biomass. Bioaccumulation, in contrast, requires a metabolic activity of the cell and often an energy expenditure for the uptake of heavy metals inside the cell. A fraction of heavy metals can be bound strongly to proteins or sequestered inside intracellular mulch vesicles, while a remainder is stored in the cell cytoplasm. Many microorganisms with metal resistance properties secrete extracellular polymeric substances and produce large polysaccharide capsules that scavenge heavy metals and provide protection against further entrance of heavy metals inside the cell. The major physiological effect of toxic metals is a general retardation of growth, but microorganisms are capable of synthesizing metallothioneins that detoxify toxic metals by sequestration inside cytosol. [15][16][17]

5.1. Biosorption

Biosorption, an effective mechanism for heavy-metal elimination, utilizes metabolically passive bacterial biomass. While not an active form of removal, biosorption demonstrates high efficiency in sequestering metals from solid matrices and aqueous solutions. Indigenous bacterial strains, preadapted to heavy metals, survive despite their contamination and consequently remove heavy metals more efficiently than nonnative species [2]. Biosorption primarily depends on the interactions between dissolved metal species and the bacterial surface, with the microbial cell wall—as the largest surface area component—facilitating metal binding. Representative heavy metals extensively studied include lead, cadmium, and mercury [18].

5.2. Bioaccumulation

Bioaccumulation specifies the metabolically driven process through which microorganisms transport and concentrate metals after initial contact. Metals are internalized and concentrated within the microbial cytoplasm. Unlike biosorption, bioaccumulation depends on the viability of the biomass because high intracellular concentrations may cause toxic effects that inhibit or kill the cells. The main drawback of this method is that many metals can significantly inhibit the growth of bacteria. Commonly employed microorganisms in bioaccumulation include Pseudomonas aeruginosa, Bacillus subtilis, Escherichia coli, and Bacillus cereus. Bioaccumulation offers the potential to provide heavier metal concentration, but the level of toxicity tolerance will limit the extent to which these metals can be removed [1].

5.3. Biotransformation

Biotransformation represents a detoxification mechanism wherein indigenous bacteria convert toxic heavy metal ions into less toxic or nontoxic forms through enzymatic reduction or methylation [1]. Metals such as chromium, mercury, selenium, and copper undergo valence state changes, often resulting in less harmful species that may exhibit altered solubility and mobility. For instance, hexavalent chromium, a potent carcinogen, can be reduced to the less toxic trivalent form, thereby mitigating its environmental threat. Sulfur O-acetyltransferase enzymes may initiate the detoxification of metals like cadmium and arsenate. The reduced solubility of biotransformed metals frequently leads to increased precipitation and subsequent removal from the solution phase.

6. Case Studies of Bioremediation

A field trial in a mining area in China compared indigenous microorganisms and non-indigenous bacteria for heavy metal removal from the soil [2]. The indigenous bacteria achieved a greater reduction of heavy metal contaminations. In a laboratory study, indigenous bacteria isolated from heavy metal contaminated soil in India were tested for removal of Cd, Cr, Cu, Ni and Zn [1]. Cadmium was most effectively removed and maximum removal efficiency was 87 %.

Other studies on indigenous bacteria also found good removal efficiencies. The Ganga basin was explored for Pseudomonas strains capable of reducing concentration of heavy metals. Two strains (AK1 and AK9) resisted five heavy metals on nutrient agar and showed maximum biosorption of metal ions from the aqueous solution. A Cd-Zn contaminant site was examined for microbial activity and the Ganga sediments and soil samples revealed that indigenous bacteria actively accumulated the metals. A biofilm-based bioremediation system was also developed for soil contaminated with heavy metals. A diverse set of indigenous bacteria can be used to remove heavy metals, since the contamination sites have been selected based on a wide range of microbial activity under the heavy-metal stress. [19][20][21]

6.1. Field Studies

Field studies conducted from 2002 to 2018 worldwide confirm that bioremediation of heavy metals is most effective when indigenous bacteria are utilized for removal from contaminated soil. Applying indigenous bacteria enhances bioremediation performance, even under high metal concentrations. Although the combined effects of concentration and exposure period on bioremediation capability are recognized, they have rarely been jointly examined in field conditions. Nevertheless, field studies suggest that in situ bioremediation coincides with a reduction of toxic metals and metalloids in contaminated soil.

Historically, heavy metal remediation has been tested under field and laboratory conditions. The strategies differ in scale and cost, with laboratory phases preceding the more expensive field studies. Site assessment informs the choice, supported by analyses of soil properties (pH; cation and anion exchange capacity, etc.), microbial populations (bacteria, fungi, archaea, and enzymes), and the metal species present. Ultimately, the field sites themselves become the source of effective indigenous bioremediation strains. Inoculation of these bacteria into the contaminated environment can then enhance heavy metal removal. [22][23][24]

6.2. Laboratory Experiments

Researchers examined the native microbial populations in soil from a site that had been heavily contaminated by a paper mill for many years, to assess their potential to reduce the concentration of heavy metals. Bacterial isolates were selected for their capacity to grow in nutrient broth containing up to 3 mM of each metal, and tested as consortia on polluted soil samples. At the end of the experiments, un-inoculated controls showed metal concentrations comparable to those found in the untreated samples, whereas the bioremediation assay on contaminated soil recorded removal efficiencies of a maximum 43% Cu, 52% Mn, 38% Zn, 35% Pb, 29% Fe, 15% Cr and 10% Ni, with a reaction mechanism dominated by biosorption by microbial cells. The capacity of exposed indigenous bacteria to remediate heavy metals from various polluted environments was also investigated. The tolerant strains were tested for their ability to reduce the concentration of chromium, lead and zinc in liquid cultures containing 1 mM of each metal, alone or in combination. Most bacterial populations documented efficient bioremediation, with the best removal capacity exhibited by a Bacillus sp. The removal of heavy metals from contaminated soil and aqueous solutions is one of the most beneficial methods reported in the literature, with indigenous bacteria potentially providing a rapid, efficient and cost-effective alternative to current technologies [2] [25].

7. Factors Influencing Bioremediation Effectiveness

Parameters such as metal ion characteristics, initial metal concentration, soil properties, temperature, nutrient availability, and the choice of microbial strain influence the effectiveness of bioremediation for heavy metal removal from contaminated soil [1]. Heavy metals alter soil texture and pH, affecting oxygen and nutrient dispersal and thus modulating the bioremediation capacity of polluted sites. Nutrient availability directly influences microbial growth and their ability to degrade pollutants [2]. The selection of a highly tolerant and resistant microbial strain is crucial to withstand and remove toxic pollutants from the contaminated environment. Temperature affects both contaminant solubility and mobility, thereby impacting biodegradation rates; oxygen availability is essential for aerobic degradation processes. Microbial-mediated bio-precipitation of metals such as uranium and chromium into insoluble forms further contributes to their remediation.

7.1. Soil Characteristics

The characteristics of soil influence the contamination of the site as well as the subsequent remediation technique [25]. bioremediation—using microbes such as Bacillus, Aspergillus, Penicillium and Rhodobacter sphaeroides—to remove or detoxify heavy metals such as chromium, lead, cadmium, zinc and copper. These toxic elements, released from anthropological activities such as mining and agriculture, must be immobilized or removed by amendments, phytoremediation or technological clean-up strategies. However, many challenges in the application of bioremediation from the laboratory to the field remain.

7.2. Environmental Conditions

Environmental conditions significantly influence the either enhancement or reduction of the microorganisms' capability to adapt to contaminated fields and to biodegrade hazardous substances [2]. Also, quite many other factors-right moisture amount, temperature variations, elemental and nutrient composition and availability, architectural properties of the soil, the contaminating element form, and pollutant accessibility-moderate heavy metal binding and liberation in polluted soil and terrestrial waters. It is for that reason that only a handful of the total organisms ground out from a polluted soil actually get involved in the remediation process [1].

7.3. Bacterial Strain Selection

The process of selecting bacterial strains is fundamental to the development and optimization of bioremediation of heavy metals in contaminated soils. Indigenous heavy metal–resistant strains are becoming increasingly preferred because they possess intense tolerance and the capacity to resist and reduce high levels of toxic elements.

Members of the genera Bacillus, Paenibacillus, and Cellulosimicrobium have been found to exhibit high potential for chromium biosorption [25]. Growth studies of isolates designated SA6, AT26, and MM40 in Luria Bertani (LB) medium supplemented with various heavy metals have demonstrated resistance to each metal, except for silver (Ag), mercury (Hg), and nickel (Ni), to which all isolates were sensitive [26]. Microorganisms exhibiting resistance to heavy metals and the capacity to biotransform them into less toxic forms therefore provide a viable means to detoxify contaminated soils.

8. Challenges and Limitations

Despite its potential as an alternative remediation technology, bioremediation using indigenous bacteria faces several challenges and limitations that impede practical application. Contaminated soils of mining origin often present a deficit in essential nutrients such as carbon, nitrogen, and phosphorus required to sustain indigenous bacterial growth and metabolic function. Due to the high sorption capacity of cell biomass, heavy metals readily adsorb onto bacterial cells, generating toxic effects that adversely affect cell viability and active participation in the remediation process. Societal and regulatory factors impose significant constraints; many countries have yet to fully develop the regulatory frameworks or public acceptance needed for widespread application of indigenous bacterial bioremediation to address heavy metal contamination in soils [1] [25]. These considerations underscore the need for an integrative approach that combines existing remediation technologies with enhanced indigenous bacterial processes to overcome these barriers and effectively reduce heavy metal concentrations in contaminated soils.

8.1. Nutrient Availability

The availability of nutrients is crucial for the growth of indigenous bacterial strains involved in bioremediation processes. Indigenous microbial communities, characterized by enhanced metal-resistance traits, are often considered suitable candidates for bioremediation because they have adapted to the existing conditions of heavy metal-contaminated environments [25]. Additionally, any limits to nutrient supply can increase the toxicity of heavy metals in the soil and reduce the effectiveness of the biotreatment [1].

8.2. Toxicity of Heavy Metals

Heavy metals påverkar organismer genom bindning till partiklar förenade med biologiska strukturer och funktioner. Många metaller utgör inga toxiska faror och är till och med nödvändiga i spormängder för många mikroorganismer. De flesta organismer anses beroende av sju metaller: järn, mangan, koppar, zink, molybden, kadmium och nickel, samtidigt som andra såsom beryllium, bor, litium och vanadin kan vara gynnsamma för vissa arter. Även om metaller som koppar och zink är essentiella i spårhöjder, blir de toxiska om de förekommer i för stora mängder. Vissa metaller som kvicksilver, kadmium och bly är giftiga även vid relativt låga halter och orsakar generell eller specialiserad toxiskitet hos mikroorganismer. Toxiciteten relaterad till överexponering skiljer sig från essentiell brist eller från rena metallallergier. Riskvärdering uppstår genom att använda biologiska system som tre indikatorer: fysiologisk toxicitet, bioackumulering av enskilda metaller och territoriell energimetabolism. Förståelse av metaller ur organismers synvinkel kräver insikt i biokemiska och molekylära mekanismer för upptag, transport, verkan och utsöndring. Många mikroorganismer utvecklar motstånd mot giftiga metaller i deras omgivning [2]. Bakteriell nedbrytning med användning av Pseudomonas genom biosorption och biotransformationstätheter erbjuder kostnadseffektivitet eftersom den eliminerar metalljoner från avloppsvatten och förorenad mark [1].

8.3. Regulatory and Public Acceptance

The widespread release of untreated effluents into natural water bodies and the disposal of untreated solid waste along roads and drainage channels have severe consequences on aquatic ecosystems and public health. Concerns related to the safety of consuming edible plants irrigated with effluents from energy plants, along with prolonged exposure to toxic chemicals found in sponge iron plant emissions, have led to opposition against the location of such industrial units in densely populated areas. These societal perceptions and apprehensions, fuelled by limited knowledge about bioremediation processes, often create challenges for regulators and policy makers tasked with monitoring and permitting these activities [2]. In addition to public skepticism, legislative bodies have not formally recognized or integrated bioremediation technologies into national pollution control progammes. The listing of available or approved technologies fails to acknowledge bioremediation as an accepted method, thereby further limiting its practical application and acceptance on a wider scale [1].

9. Future Directions in Bioremediation Research

Advances in bacterial strain manipulation emerge as a focal point in future research. Employing bioinformatics tools assists in identifying proteins and candidate genes related to bacterial resistance and remediation capabilities. Genetic engineering of bacterial hosts enables the de novo synthesis of biofilm components, mechanisms linked to heavy-metal remediation [27]. Further progress might be achieved through transgenic-expression technologies and genome-tailoring tools to enhance pre-existing bacterial strains.

At the field scale, integration of indigenous bacteria within a multistep bioremediation process, possibly in combination with more conventional techniques, appears to be the likely direction for practical application [1]. Such efforts would face common field-scale challenges, including the need to optimize nutrient levels to support metabolic activity and to mitigate toxic metal concentrations that inhibit growth [25]. Addressing these challenges remains necessary to unlock the full remedial potential of indigenous bacteria for heavy-metal-contaminated soils.

9.1. Genetic Engineering of Bacteria

Genetic engineering offers promising avenues for enhancing the bioremediation efficiency of indigenous bacteria in heavy metal-contaminated environments. The introduction of metal resistance genes into cultivable strains has enabled the removal of mercury (Hg), cobalt (Co), zinc (Zn), and lead (Pb) from aqueous environments [25]. Nasl Seraji et al. successfully grafted a chromosomal DNA fragment containing mercury resistance determinants from a Mercuric Chloride-tolerant bacterium into Pseudomonas putida OK60, resulting in efficient bioremediation of mercury over a wide temperature range and improved capabilities at higher salinities. Multicomponent recombinant systems constructed from hyper-resistant strains hold considerable promise for detoxifying sites polluted with multiple heavy metals. Furthermore, the essential genes mghA, merB, and merG from Pseudomonas mercury reductase systems have been used for the genetic transformation of strains with high bioremediation potential but lacking metal resistance [27].

9.2. Integration with Other Remediation Techniques

Heavy metals accumulation has resulted in serious concern for the environment and living organisms. Bioremediation is a technique that uses indigenous microorganisms either separately or in combination with plants or chemical compounds to reduce toxicity, bioavailability and volume of contaminants and convert them to less toxic compounds. The resin from Phyllanthus emblica (PE) is able to remove simultaneously Zn(II), Cr(V I), Cu(II), Before application of a single remediation technique, the characteristics of the site must be considered for the design. It is challenging to remove heavy metals because they are non-degradable metals, persistent to chemical and biological degradation, and can be toxic. Nanoparticles are able to penetrate deeper into the contaminant than the conventional injection, which results in a higher reaction rate. Application of versatile indigenous bacteria isolates (Bacillus pumilus and Bacillus cereus) to enrich metals as well as to support metal accumulative plants such as Ligustrum robustum Blume has been studied. All indigenous bacterial species utilized in the study demonstrated a satisfactory level of field treatment [25].

Most bioremediation processes are based on the ability of microorganisms to transform the chemical structure and, ultimately, the toxicity of hazardous molecules and/or to accumulate the target pollutants inside the cells. Yet, the success of the process is strongly dependent on the efficiency of the strains to sustain in the contaminated environment and to cope with the various contaminants present. Otherwise, the technique of bioremediation by indigenous bacteria becomes versatile and competitive for the elimination of heavy metals pollution from the contaminated soils [2].

10. Conclusion

The existence of harmful contaminants such as organic materials, heavy metals, and synthetic chemicals in soil leads to severe health problems and environmental deterioration. Other techniques to control contaminants in soil include addition of chemicals and landfill disposal. Bioremediation is a cost-effective, eco-friendly, and generally accepted technology used for the treatment of contaminated soil by employing biological agents such as bacteria, fungi, and algae. Among these biological agents, bacteria gained much significance due to their high metabolic activities in different environmental conditions. Both the dead and living biomasses can uptake heavy metals through metal-binding proteins in the cell wall. Bioremediation of heavy metals from contaminated soil by indigenous bacteria is a relatively simple, economic, and easy technique useful as an efficient way for the removal of heavy metal ions. Indigenous bacteria have been found to be more effective for the recovery or removal of heavy metals with indigenous strains being more competent compared to other non-indigenous strains. This result suggests that bioremediation through indigenous bacteria is a promising approach for the cleaning up of heavy metals from sites contaminated with active metals.

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