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Current and Future Perspective of Bioremediation Approach for Heavy Metal Detoxification of Wastewater

Priyanka Gupta[1], Gaurav Tamrakar[2]
[1]Assistant Professor, Department of Chemistry, Kalinga University, Naya Raipur, Chhattisgarh, India
[2]Assistant Professor, Department of Mechanical Engineering, Kalinga University, Naya Raipur, Chhattisgarh, India
Corresponding email id: [1] priyanka.gupta@kalingauniversity.ac.in,
[2]gaurav.tamrakar@kalingauniversity.ac.in

Abstract

As a consequence of the on-going rise of the manufacturing sector, the presence of heavy metals in aquifers has become a significant ecological issue on a global level. As a consequence, there is a greater necessity for eliminating toxic metals from effluent. Conventional methods for remediation had a number of drawbacks, including high costs and an enormous amount of harmful waste production that resulted in additional sources of contamination. Thus, it is recommended to eliminate pollutants from sewage before using it for agricultural purposes by using green technology that is economical to use and not harmful to the environment. In this overview, the most recent research on the bioremediation processes of toxic metals in industrial effluent is reviewed. The presence of heavy metals, contamination of the environment, and the capability of microorganisms to modify their behaviour have all been reported to be responsible for significant alterations in microbial diversity. This study explores the essential resistance mechanisms microbes use to engage in persistent metal pollutants while also highlighting the possible capability of microorganisms to remediate toxic metals in the context of protecting the environment. Additionally, the present research assessed the bioremediation capabilities of algae, fungi, bacteria, biofilms, and genetically engineered microorganisms for the elimination of these harmful heavy metals. The detoxification of toxic metals has grown significantly with the use of such methods as green technology in the coming decades.

Keywords: Waste water, heavy metals, bioremediation, microorganisms, mechanism

1. Introduction

Heavy metal poisoning of the water, soil, and air has become one of the most devastating effects now harming mankind [1]. According to Kumar et al. (2015), toxic metals are characterised as metallic chemical elements with a significant quantity that are hazardous, do not breakdown biologically, and pollute the environment. Very few of such contaminants, although they constitute significant sources of nourishment for vegetation, microbes, and mammals at lower concentrations[16, 4]. Due to their biologic accumulation and lack of biological degradation in nature, metals are potentially dangerous for the ecosystem and serve as serious threats to health .For metabolism and redox processes, a number of inorganic metals, including Mg, Ni, Cr^{3+}, Cu, Ca, Mn, Na, and Zn, are essential elements that must be present in trace amounts. Aluminium, lead, cadmium, gold, mercury, and silver are examples of toxic metals that are harmful for living beings but do not serve any biological purpose[10].

Huge amounts of toxic metals are discharged into the ecosystem by human beings and manufacturing processes such as fossil fuel combustion, mineral extraction, electrolysis, and wastes produced by the textile, auto, chemical-based, steel, and oil and gas industries. As well as toxic metals, they are released through ecological processes such as eruptions of volcanoes, oceanic aerosols, organic materials breaking down naturally, and wind erosion[13].In both urban and rural parts of India, ground and surface water are essential and primary sources of drinking water. One of the most significant components of ground research is determining water quality because it has qualities that surface water does not, ground water is highly valued. People have used ground water as a source of drinking water for thousands of years, and more than half of the world's population still relies on it for survival. Ground water is valuable not just because of its widespread occurrence and availability, but also because of its persistent high quality, making it an excellent supply of drinking water[8].The chemical composition of groundwater is a measure of its suitability as a source of water for human and animal consumption, irrigation, and for industrial and other functions [7]. Therefore, monitoring the purity of water is crucial because water is necessary for human fitness and the reliability of aquatic ecosystems [8].Groundwater with a high contamination level has more nutrients in it, which can change the pH level as well as the physical and chemical properties of reservoirs. As a result of these water quality changes, microbial communities become more resistant to contaminants such as heavy metals and antibacterial drugs[23].

Biochemical precipitation, membrane filtration, ion exchange flocculation, electrochemical methods, and the coagulation process are some of the traditional methods used to remove contaminants such as heavy metals from effluent the drawbacks of these methods include high operating and servicing expenses, along with residual contamination caused by the production of harmful waste. At extremely low quantities of heavy metals, notably below 100 mg/L, the majority of these approaches are also costly and unsuccessful [12, 15]. Alternative methods that are harmless to the environment and have no negative impacts are also being developed for remedying these disadvantages (poor efficiency and bad consequences) The methods described above, known by the name of "bioremediation techniques," may be performed by utilising microbes like fungi, bacteria, or vegetation. According to Ayangbenro and Babalola (2017), these kinds of organisms may absorb toxic metals or convert them by altering their valence state, which makes them less harmful. The primary goal of the current review paper is to examine the numerous biological remediation methods utilised by various microorganisms to reduce the contamination of heavy metals. This article goes into great length about the harmful effects of the four most prevalent heavy metals (As, Pb, Hg, and Cr) on human health as well as their methods of remediation.

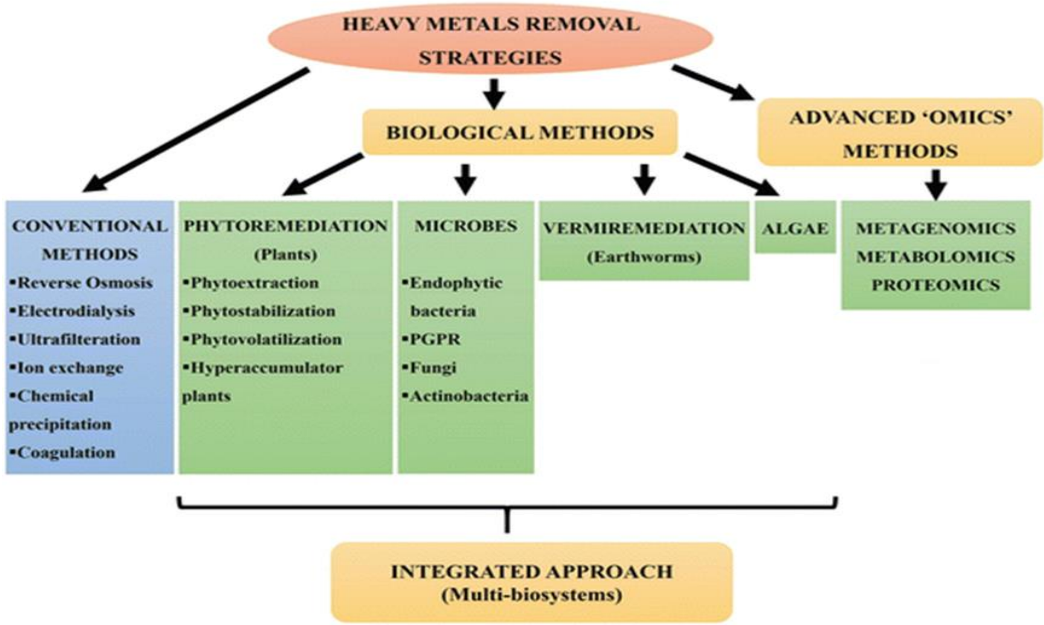


Fig. 1 An outline of the remedial strategies applied for bio removal of heavy metals [3].

2. Heavy metals as a pollutant and their effect on health

Heavy metal is produced by many different sources, including mining, industry, and agriculture and thatare a threat that has been growing at a steady rate and has harmful effects on the environment [12].The physiological processes of humans and the ecosystem as a whole are harmed by heavy metals. They have a strong affinity for other elements, which includes sulphur, and can bind to the functional group of a protein to inhibit its activity in living tissues. Ions of cadmium, lead, and mercury exhibit the capability to adhere to the membranes of cells and inhibit cell transportation Metals that are toxic promote the synthesis of oxygen-based reactive species as well as free radicals, which can lead to cell oxidative damage. They are not disposable and usually bio concentrates or accumulates in the tissues of organisms. Exposure to metals can harm or impair the brain and central nervous system, diminish the level of energy, change the circulatory system's chemical composition, and affect the kidneys, lungs, and other essential organs. Exposure for a long time can lead to gradually occurring physical, muscle-bound, and cerebral degenerative diseases that resemble diseases such as Parkinson's disease, multiple sclerosis, Alzheimer's disease, and muscular dystrophy. Long-term exposure to some metals or their compounds can cause allergies [25].

2.1Chromium

Chromium (Cr), a found in nature element which is extensively used in industrial operations, is among the most toxic and hazardous metals. Water contamination might result through industrial machinery polishing, inappropriate residual mining material handling, or Cr (IV) leaks from chromite mines [9].Chromium has the ability to undergo number of changes in the water habitats through the mechanisms of adsorption, desorption, redox, solubility, and precipitation. Chromium is one of the most dangerous toxins that are detrimental to a living thing, cancerous to humans, and non-biodegradable [17].

2.2Arsenic

Due to the mobilisation of As in groundwater and aquifers, the contamination of As can spread improperly into the water bodies. Humans who are exposed to high quantities of As may experience a range of health issues, including genetic damage, anaemia, and other issues. Investigations have also revealed problems with the nasal passages, cardiovascular and neurological diseases, consequences of diabetes, skin diseases, and aberrant babies as a consequence of consuming As-contaminated water[9].

2.3Cadmium

Cadmium (non-degradable) ions mostly contain considerable toxicities and are ingested by organisms through food, making it difficult to remove and leading to biological harm. Health Organization has declared that the maximum amount of Cd in blood should not exceed 0.005 mg/L due to all these health concerns [17].

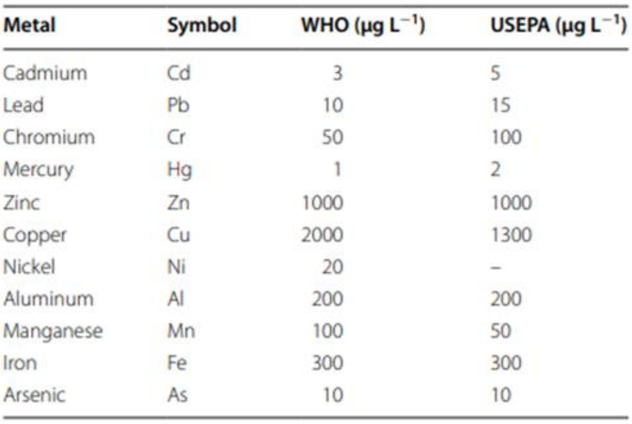
2.4Nickel

Potable water tests obtained from different sources have revealed Ni pollution. Although plumbing materials are the primary contributor of nickel in freshwater resources, minerals that possess nickel may cause it to leak into groundwater [9].Pb accumulates inside the organs (i.e., mind), which may also lead to poisoning (plumbism) or even death. The gastrointestinal tract, kidneys, and vital nervous gadget are also stricken by the presence of lead. Youngsters exposed to steer are at risk for impaired development, lower IQ, shortened interest span, hyperactivity, and mental deterioration, with youngsters under the age of six being at extra sizable chance [7].

2.5Mercury

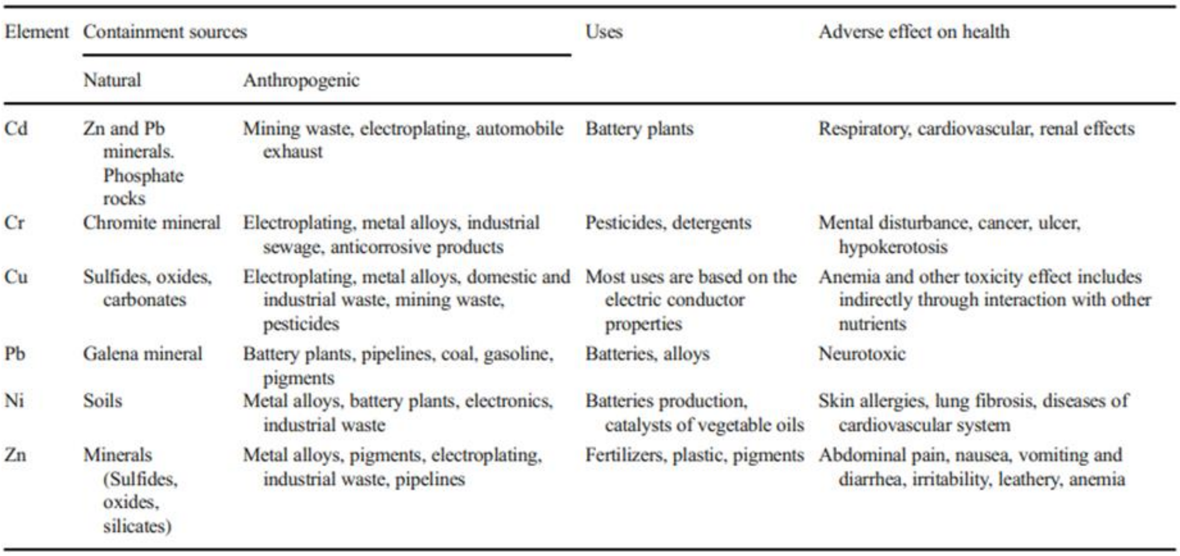
The metal mercury can move through water systems and build up in ecosystems. It causes a variety of environmental issues because it is so prevalent in the environment to protect the environment and human health from mercury [9].

Table 1.Permissible limits for heavy metals in water according to WHO and USEPA[1].



Metal	Symbol	WHO (μg L^{-1})	USEPA (μg L^{-1})
Cadmium	Cd	3	5
Lead	Pb	10	15
Chromium	Cr	50	100
Mercury	Hg	1	2
Zinc	Zn	1000	1000
Copper	Cu	2000	1300
Nickel	Ni	20	–
Aluminum	Al	200	200
Manganese	Mn	100	50
Iron	Fe	300	300
Arsenic	As	10	10

Table 2. Contamination sources, uses, and adverse health effects of some heavy metals [20].



Element	Containment sources		Uses	Adverse effect on health
	Natural	Anthropogenic		
Cd	Zn and Pb minerals. Phosphate rocks	Mining waste, electroplating, automobile exhaust	Battery plants	Respiratory, cardiovascular, renal effects
Cr	Chromite mineral	Electroplating, metal alloys, industrial sewage, anticorrosive products	Pesticides, detergents	Mental disturbance, cancer, ulcer, hypokerotosis
Cu	Sulfides, oxides, carbonates	Electroplating, metal alloys, domestic and industrial waste, mining waste, pesticides	Most uses are based on the electric conductor properties	Anemia and other toxicity effect includes indirectly through interaction with other nutrients
Pb	Galena mineral	Battery plants, pipelines, coal, gasoline, pigments	Batteries, alloys	Neurotoxic
Ni	Soils	Metal alloys, battery plants, electronics, industrial waste	Batteries production, catalysts of vegetable oils	Skin allergies, lung fibrosis, diseases of cardiovascular system
Zn	Minerals (Sulfides, oxides, silicates)	Metal alloys, pigments, electroplating, industrial waste, pipelines	Fertilizers, plastic, pigments	Abdominal pain, nausea, vomiting and diarrhea, irritability, leathery, anemia

3. Principle of bioremediation

This means that biological remediation is an integrated approach that integrates organisms such as fungi, bacteria, plants,actinomycetes, and algae, all of which might be utilised as a type of biological agent for decontaminating metals that are toxic [1].According to Ayangbenro and Babalola (2017), microbes effectively disintegrate or convert the complex and harmful pollutant into the less poisonous. In order to completely grow and produce numerous catalysts as additional compounds, the native microorganisms in areas of contamination must be stimulated by the introduction of additional food and favourable conditions for development. The complicated pollutant is effectively broken down into simpler ones by such metabolites [1].

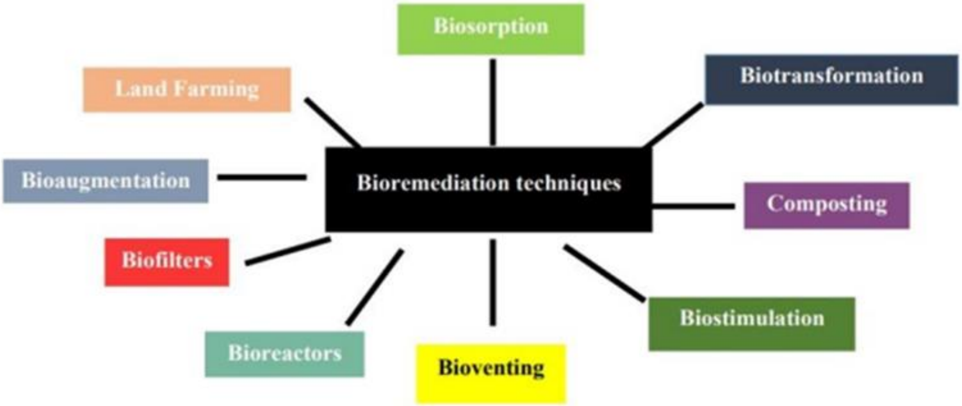
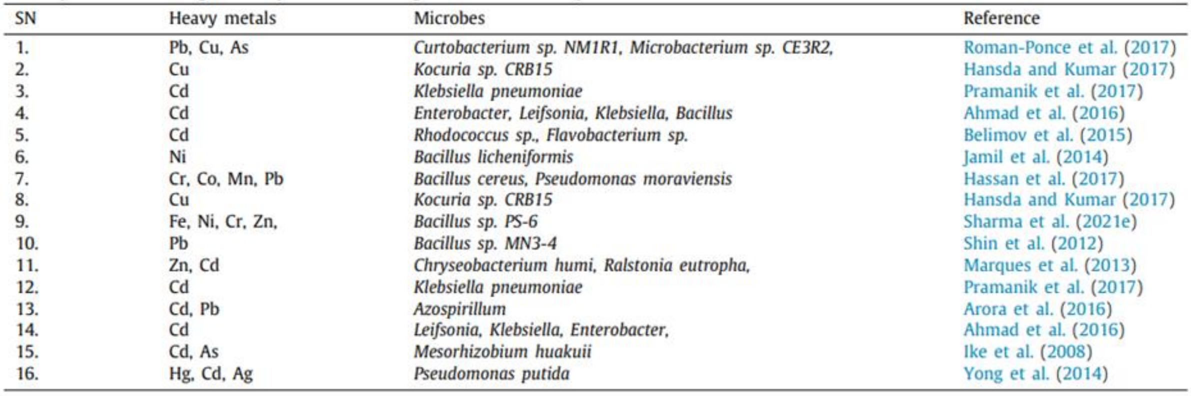


Fig. 2.Various kinds of bioremediation methods [24].

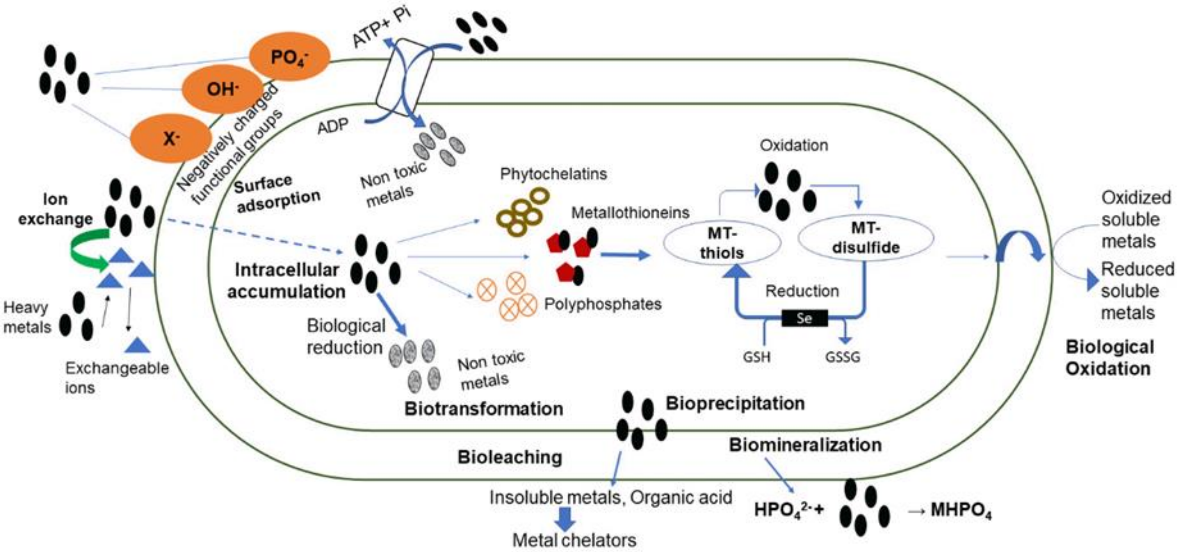
Table 3.List of possible microbes that have significant heavy metal resistance that have been identified [10].



SN	Heavy metals	Microbes	Reference
1.	Pb, Cu, As	*Curtobacterium sp. NM1R1, Microbacterium sp. CE3R2,*	Roman-Ponce et al. (2017)
2.	Cu	*Kocuria sp. CRB15*	Hansda and Kumar (2017)
3.	Cd	*Klebsiella pneumoniae*	Pramanik et al. (2017)
4.	Cd	*Enterobacter, Leifsonia, Klebsiella, Bacillus*	Ahmad et al. (2016)
5.	Cd	*Rhodococcus sp., Flavobacterium sp.*	Belimov et al. (2015)
6.	Ni	*Bacillus licheniformis*	Jamil et al. (2014)
7.	Cr, Co, Mn, Pb	*Bacillus cereus, Pseudomonas moraviensis*	Hassan et al. (2017)
8.	Cu	*Kocuria sp. CRB15*	Hansda and Kumar (2017)
9.	Fe, Ni, Cr, Zn,	*Bacillus sp. PS-6*	Sharma et al. (2021e)
10.	Pb	*Bacillus sp. MN3-4*	Shin et al. (2012)
11.	Zn, Cd	*Chryseobacterium humi, Ralstonia eutropha,*	Marques et al. (2013)
12.	Cd	*Klebsiella pneumoniae*	Pramanik et al. (2017)
13.	Cd, Pb	*Azospirillum*	Arora et al. (2016)
14.	Cd	*Leifsonia, Klebsiella, Enterobacter,*	Ahmad et al. (2016)
15.	Cd, As	*Mesorhizobium huakuii*	Ike et al. (2008)
16.	Hg, Cd, Ag	*Pseudomonas putida*	Yong et al. (2014)

4.Potential applications of microorganism in heavy metal bioremediation

Different interactions and survival strategies are used by microbes when inorganic elements are present. Extrusion, biological transformation, the utilisation of enzymes that break down, and the synthesis of exopolysaccharides are some of the techniques utilised by microorganisms to protect themselves from exposure to metals. By valence conversion, their volatilization or intracellular precipitation of chemicals, microbes are capable of eliminating heavy metals. Due to the fact that they have anions, which enable them to attach to metallic cations, microbes possess a negative electrical charge on the outermost layer of their cellular structures .The alcohol, hydroxyl,amine, carboxyl,thioether, phosphoryl, ester, sulfonate, sulfydryl, and thiol groups have a negative charge. Microbial sites that participate in metal sorption [10].



Oval shapes represents the heavy metals; MT- represents as Metallothioneins; Se-Compound is amplifier of thionin-reduction; GSH-Glutathione; GSSG-Glutathione disulfide

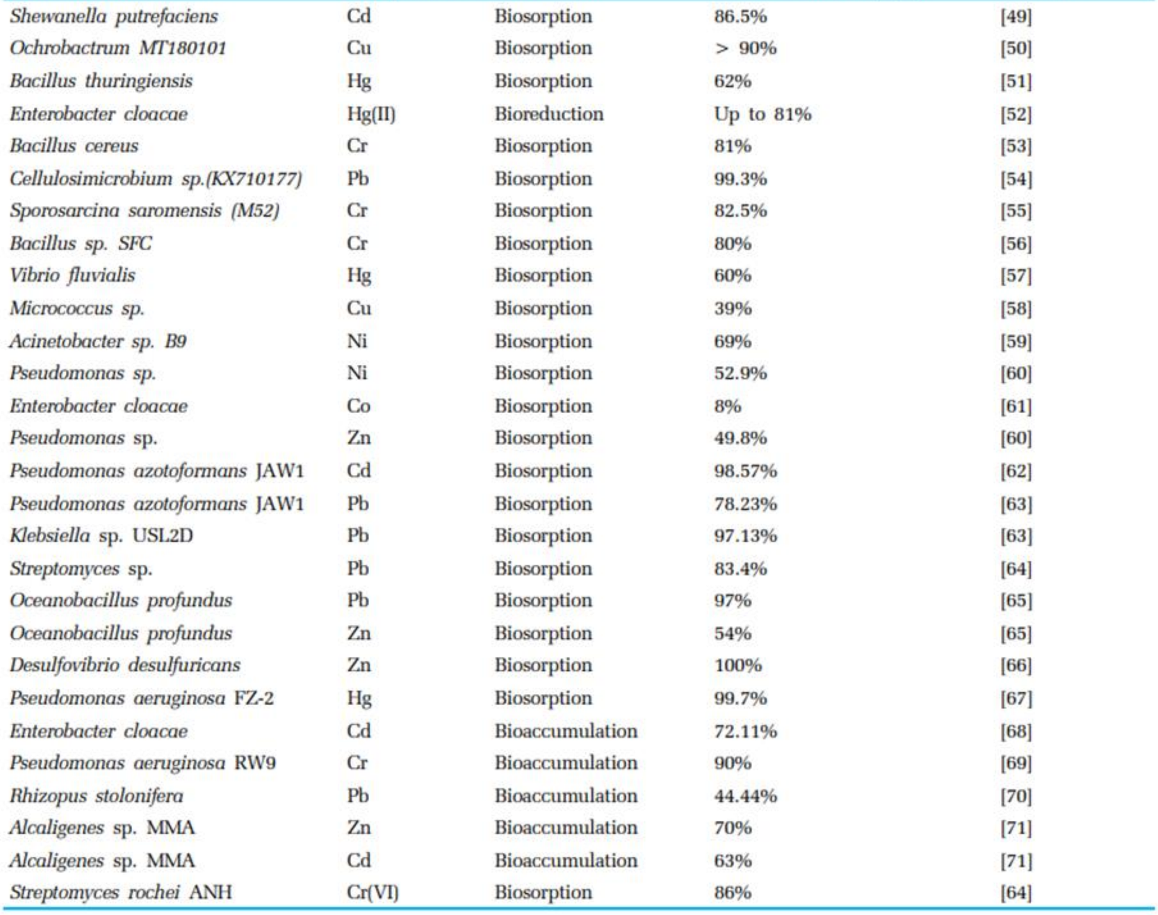
Fig.3 Microorganism bioremediation process[13].

4.1Bacteria as Bioremediation agent:

There has been a lot of research done globally on bacterial resistance to heavy metals. Resistance to heavy metals has been noted in a variety of bacterial species (Table 4). The majority of the bacterial species that pose the greatest potential alternatives for biological remediation of toxic metals belong to the genera Streptomyces and Pseudomonas. Using techniques including bio stimulation, bio augmentation, and bio attenuation, contaminants can be bio remediated [18].

Recognising how bacteria interact with their surroundings, particularly with ions containing heavy metals, depends greatly on microbial surface structures [25].Metals including copper, zinc, lead, cadmium, and chromium can be quickly removed using bacterial biomass. Due to the varied cellular architecture of various kinds of bacteria in terms of peptidoglycans such as N-acetylmuramic acid and poly-N-acetylglucosamine, bio sorption efficiency depends on the presence of heavy metal ions. The main structural interaction between metal ions and the bacterial biomass is through the cell wall of the bacteria. A metal binding ability can be acquired on or within the cell wall by the total negative charge caused by anionic functional compounds (such as sulphate, hydroxyl, carboxyl, amine, and phosphate) that exist in gramme-positive and gramme-negative bacteria. Dead feedstock cells remove heavy metals by outside mechanisms. These interactions are caused by functional groups on the outer layer of cells, such as amine, phosphate, carboxyl, and hydroxyl ones [27].By complexing, those with carboxyl groups can bind cadmium to the surface. The amino groups have proven effective in binding and electrostatic interaction, eliminating of Chromium. Just before adopting microorganisms for biological remediation, species of bacteria require being subjected to pollutants for catalytic stimulation. To start the process of essential enzymatic expression, a low pollutant level is required. Bioremediation is currently carried out using bacteria including Desulfovibrio, Bacillus, Pseudomonas, and Geobacte[14]. It has been investigated how well heavy metal-resistant microorganisms extracted from samples of the environment perform in bioremediation procedures. It has been proven that Cupriavidus metallidurans CH34 can remove toxic metals from contaminated water as well as soil. Through reactive mechanisms, this type of bacteria has the ability to store selenium, gold, and volatile mercury [25].

Table 4.Efficacy of various strains of bacteria in decontamination of toxic metal[13].



Bacterial Strain	Heavy metals	Mechanism	Removal Efficiency (%)	References
Shewanella putrefaciens	Cd	Biosorption	86.5%	[49]
Ochrobactrum MT180101	Cu	Biosorption	> 90%	[50]
Bacillus thuringiensis	Hg	Biosorption	62%	[51]
Enterobacter cloacae	Hg(II)	Bioreduction	Up to 81%	[52]
Bacillus cereus	Cr	Biosorption	81%	[53]
Cellulosimicrobium sp.(KX710177)	Pb	Biosorption	99.3%	[54]
Sporosarcina saromensis (M52)	Cr	Biosorption	82.5%	[55]
Bacillus sp. SFC	Cr	Biosorption	80%	[56]
Vibrio fluvialis	Hg	Biosorption	60%	[57]
Micrococcus sp.	Cu	Biosorption	39%	[58]
Acinetobacter sp. B9	Ni	Biosorption	69%	[59]
Pseudomonas sp.	Ni	Biosorption	52.9%	[60]
Enterobacter cloacae	Co	Biosorption	8%	[61]
Pseudomonas sp.	Zn	Biosorption	49.8%	[60]
Pseudomonas azotoformans JAW1	Cd	Biosorption	98.57%	[62]
Pseudomonas azotoformans JAW1	Pb	Biosorption	78.23%	[63]
Klebsiella sp. USL2D	Pb	Biosorption	97.13%	[63]
Streptomyces sp.	Pb	Biosorption	83.4%	[64]
Oceanobacillus profundus	Pb	Biosorption	97%	[65]
Oceanobacillus profundus	Zn	Biosorption	54%	[65]
Desulfovibrio desulfuricans	Zn	Biosorption	100%	[66]
Pseudomonas aeruginosa FZ-2	Hg	Biosorption	99.7%	[67]
Enterobacter cloacae	Cd	Bioaccumulation	72.11%	[68]
Pseudomonas aeruginosa RW9	Cr	Bioaccumulation	90%	[69]
Rhizopus stolonifera	Pb	Bioaccumulation	44.44%	[70]
Alcaligenes sp. MMA	Zn	Bioaccumulation	70%	[71]
Alcaligenes sp. MMA	Cd	Bioaccumulation	63%	[71]
Streptomyces rochei ANH	Cr(VI)	Biosorption	86%	[64]

4.2Fungal bioremediation

Due to their exceptional abilities for metal absorption and recovery, fungi are frequently utilised as bio sorbents for the elimination of hazardous metals .The majority of investigations revealed that both living and dead fungus cells significantly influence how inorganic compounds adhere[10].The cell walls of fungi are primarily made of cellulose, chitin, glucan, and mannan; in addition, they have lipids, proteins, pigments that are present, and polyphosphates.Without any form of metabolic regulation, toxins may be passively taken up by the cell membrane constituents [24].

Mycoremediation uses fungi, either alive or dead, to remove pollutants from various ecological habitats. The technique of mycoremediation is economical and leaves no toxic residue behind [14].The potential of Coprinopsis atramentaria to metabolise 76% of Cd^{2+} at a concentration of 1 mg L^{-1} Cd^{2+} and 94.7% of Pb^{2+} at a concentration of 800 mg L^{-1} Pb^{2+} has been evaluated. As a result, it has been proven to be a reliable heavy metal ion accumulator for mycoremediation. According to Park and his co-authors harmful Cr (VI) might be changed into less toxic or harmless chromium (III) using decomposing fungal biomass from Aspergillus niger,Saccharomyces cerevisiae, Rhizopus oryzae, and Penicillium chrysogenum. Candida sphaerica generated bio surfactants exhibiting removal rates of 95%, 90%, and 79% for iron, zinc, and lead, respectively, according to Luna et al. The ions of metal and such lipids might interact to form complexes [10].

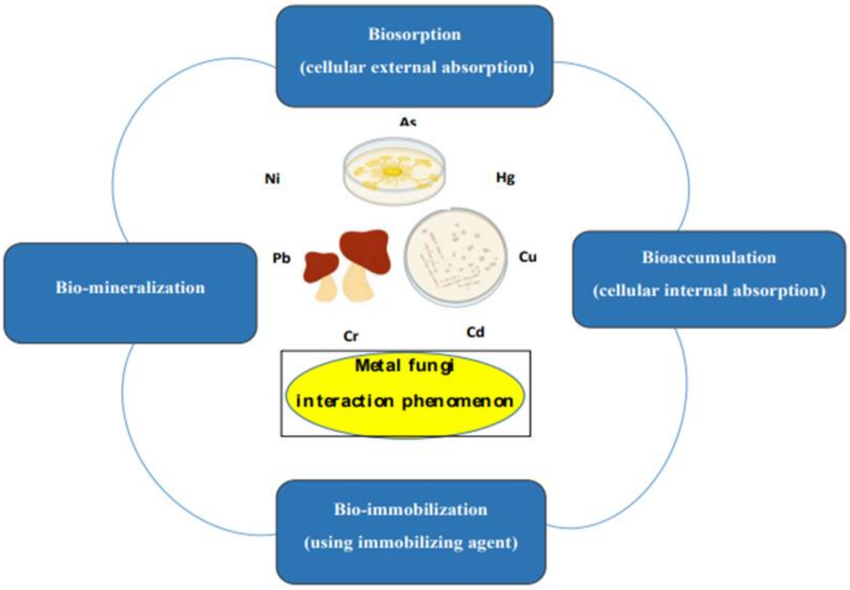
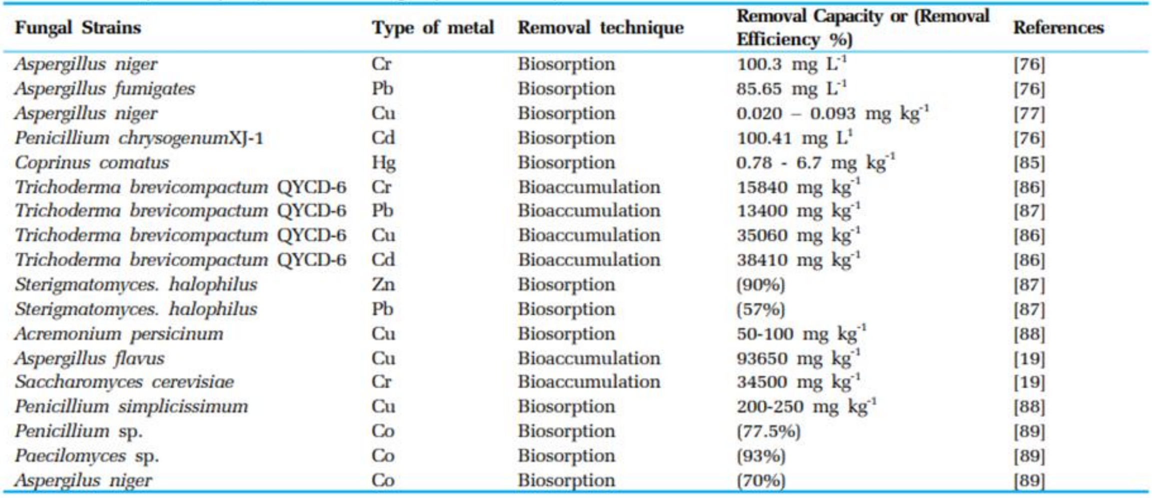


Fig.4.Primary fungal methods for removing heavy metals [24].

Table 5. Metal Absorption Capability of various fungi species to detoxify harmful metals[10].



Fungal Strains	**Type of metal**	**Removal technique**	**Removal Capacity or (Removal Efficiency %)**	**References**
Aspergillus niger	Cr	Biosorption	100.3 mg L^{-1}	[76]
Aspergillus fumigates	Pb	Biosorption	85.65 mg L^{-1}	[76]
Aspergillus niger	Cu	Biosorption	0.020 – 0.093 mg kg^{-1}	[77]
*Penicillium chrysogenum*XJ-1	Cd	Biosorption	100.41 mg L^{1}	[76]
Coprinus comatus	Hg	Biosorption	0.78 - 6.7 mg kg^{-1}	[85]
Trichoderma brevicompactum QYCD-6	Cr	Bioaccumulation	15840 mg kg^{-1}	[86]
Trichoderma brevicompactum QYCD-6	Pb	Bioaccumulation	13400 mg kg^{-1}	[87]
Trichoderma brevicompactum QYCD-6	Cu	Bioaccumulation	35060 mg kg^{-1}	[86]
Trichoderma brevicompactum QYCD-6	Cd	Bioaccumulation	38410 mg kg^{-1}	[86]
Sterigmatomyces. halophilus	Zn	Biosorption	(90%)	[87]
Sterigmatomyces. halophilus	Pb	Biosorption	(57%)	[87]
Acremonium persicinum	Cu	Biosorption	50-100 mg kg^{-1}	[88]
Aspergillus flavus	Cu	Bioaccumulation	93650 mg kg^{-1}	[19]
Saccharomyces cerevisiae	Cr	Bioaccumulation	34500 mg kg^{-1}	[19]
Penicillium simplicissimum	Cu	Biosorption	200-250 mg kg^{-1}	[88]
Penicillium sp.	Co	Biosorption	(77.5%)	[89]
Paecilomyces sp.	Co	Biosorption	(93%)	[89]
Aspergilus niger	Co	Biosorption	(70%)	[89]

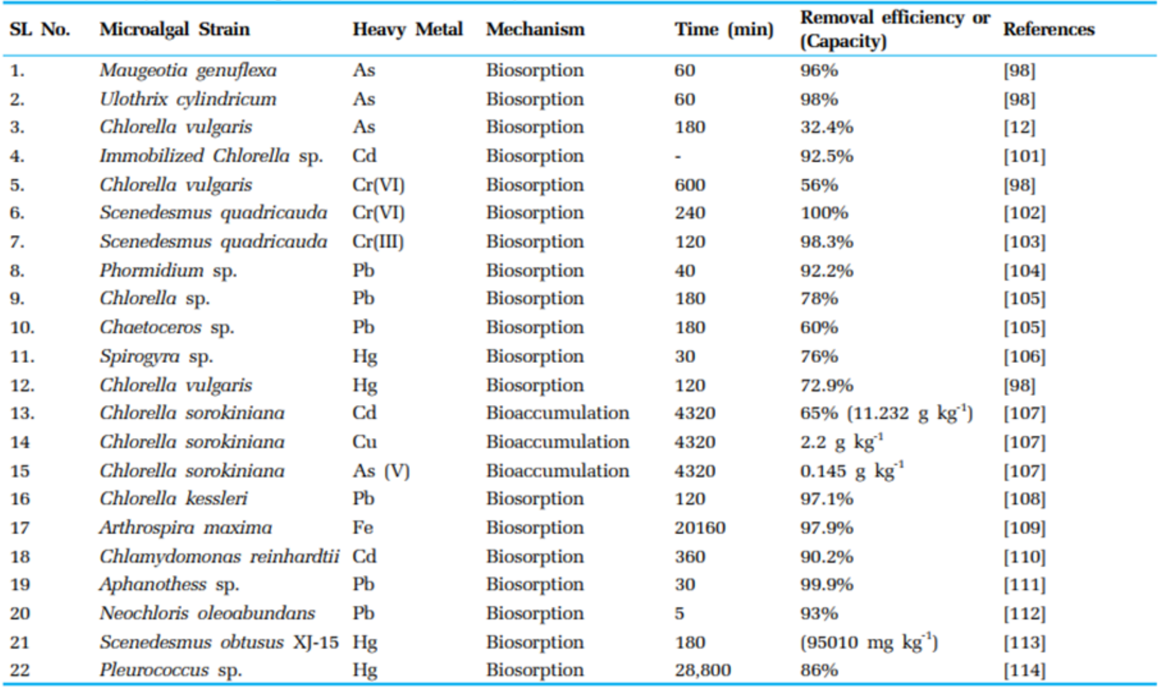
4.3 Fungal nanoparticles–mediated heavy metal remediation

The material that possesses a Nano scale exterior dimension, internal framework, or exterior structure is referred to as a nanomaterial. Nanomaterial can differ from larger-sized materials in terms of their chemical or physical qualities. Nanoparticles have been purposefully developed to eliminate contaminants from water, particularly toxic metals, harmful organic colours, greasy waste, and several agro- and commercial-industrial wastes. Using greenly synthesised fungal nanoparticles, the growth of technology has a special use in identifying the presence of contaminants such as heavy metals Because of their resistance to and ability to bio accumulate metals, fungi are particularly engaged in the biogenic synthesis of metal nanoparticles Several fungi have been used to synthesise a number of nanoparticles made of gold and silver [21]. Fungi can also make various metal nanoparticles that may absorb harmful metals from the environment. Particles like these may additionally be used as biosensors to aid with environmental remediation [24].

4.4Algal bioremediation (Phytoremediation)

Algal species are organisms that are autotrophic and produce a large amount of biomass that has few nutritional needs. Rhodophyta,Phaeophyta, and Chlorophyta, or green, brown, and red algae, respectively, have been observed to have the best bio sorption ability (phytoremediation) of each of the three algal categories. The form and composition of the algae biomass, the amount of charge, and the chemical composition of the toxic metal ion all affect the use of bio sorption in different ways. For in-situ cleaning up, several algae in live or dead species have been utilised individually or in combination, in batches or columns. Possible metal deposits in algal proteins include sulphate, hydroxyl,amine, carboxyl, and phosphate, which function by forming complexes throughout heavy metal elimination[14].

Table 6.Effectiveness of several algal strains in the elimination of heavy metals removal[13].



SL No.	Microalgal Strain	Heavy Metal	Mechanism	Time (min)	Removal efficiency or (Capacity)	References
1.	*Maugeotia genuflexa*	As	Biosorption	60	96%	[98]
2.	*Ulothrix cylindricum*	As	Biosorption	60	98%	[98]
3.	*Chlorella vulgaris*	As	Biosorption	180	32.4%	[12]
4.	*Immobilized Chlorella* sp.	Cd	Biosorption	-	92.5%	[101]
5.	*Chlorella vulgaris*	Cr(VI)	Biosorption	600	56%	[98]
6.	*Scenedesmus quadricauda*	Cr(VI)	Biosorption	240	100%	[102]
7.	*Scenedesmus quadricauda*	Cr(III)	Biosorption	120	98.3%	[103]
8.	*Phormidium* sp.	Pb	Biosorption	40	92.2%	[104]
9.	*Chlorella* sp.	Pb	Biosorption	180	78%	[105]
10.	*Chaetoceros* sp.	Pb	Biosorption	180	60%	[105]
11.	*Spirogyra* sp.	Hg	Biosorption	30	76%	[106]
12.	*Chlorella vulgaris*	Hg	Biosorption	120	72.9%	[98]
13.	*Chlorella sorokiniana*	Cd	Bioaccumulation	4320	65% (11.232 g kg^{-1})	[107]
14	*Chlorella sorokiniana*	Cu	Bioaccumulation	4320	2.2 g kg^{-1}	[107]
15	*Chlorella sorokiniana*	As (V)	Bioaccumulation	4320	0.145 g kg^{-1}	[107]
16	*Chlorella kessleri*	Pb	Biosorption	120	97.1%	[108]
17	*Arthrospira maxima*	Fe	Biosorption	20160	97.9%	[109]
18	*Chlamydomonas reinhardtii*	Cd	Biosorption	360	90.2%	[110]
19	*Aphanothess* sp.	Pb	Biosorption	30	99.9%	[111]
20	*Neochloris oleoabundans*	Pb	Biosorption	5	93%	[112]
21	*Scenedesmus obtusus* XJ-15	Hg	Biosorption	180	(95010 mg kg^{-1})	[113]
22	*Pleurococcus* sp.	Hg	Biosorption	28,800	86%	[114]

Along with metals that are toxic, microalgae consist of reactive molecules with effective binding regions that may produce compounds with pollutants in sewage. This results in flocculation, which lowers the levels of total solids that are dissolved Microalgae eliminate contaminants in two phases. The first stage is the quick external passive adsorption, and the second is the gradual intracellular positive transport and build-up. The main components of the microalgae cell wall are carbohydrates (cellulose and alginate), fatty acids, and organic proteins. These components also contain a variety of functional groups that can bind metals that are toxic, including carboxyl, hydroxyl,amino, phosphate, imidazole,sulfonate, thiol, and others [18]. Additionally, they include a large number of monomeric alcohols, laminarin, deprotonated sulphate, and carboxyl groups, all of which are attracted to charged toxic metal ions. In microalgae biomass, these various functional groups and EPS aid in the effective use of bio sorption of toxic metals [13].

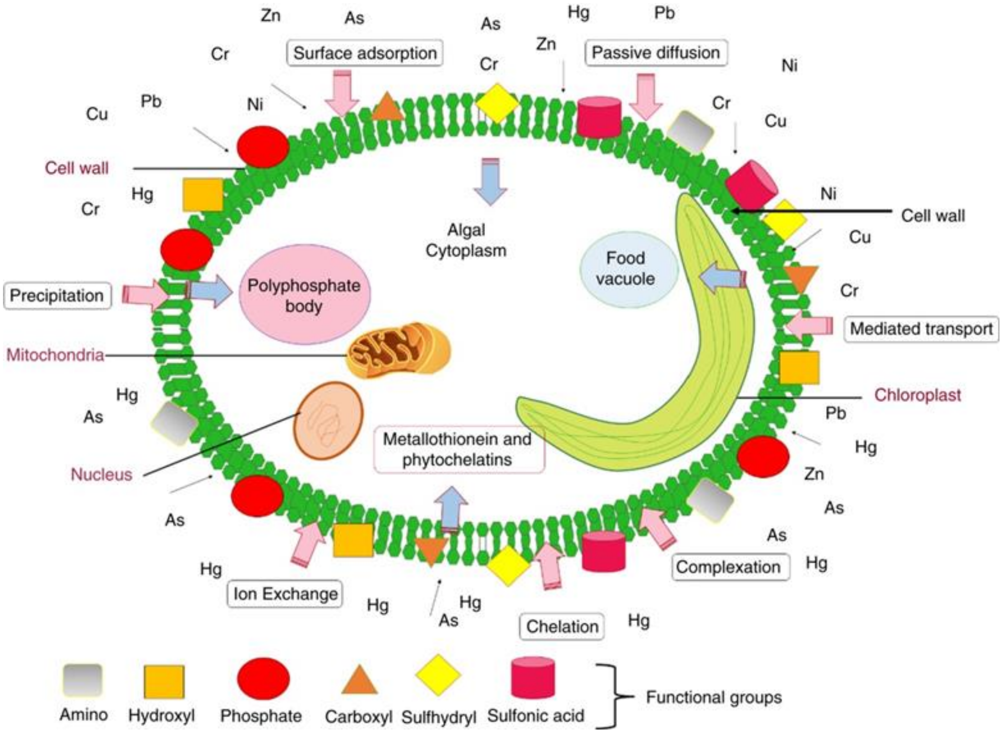


Fig. 5Method of absorption of heavy metals by microalgae[4].

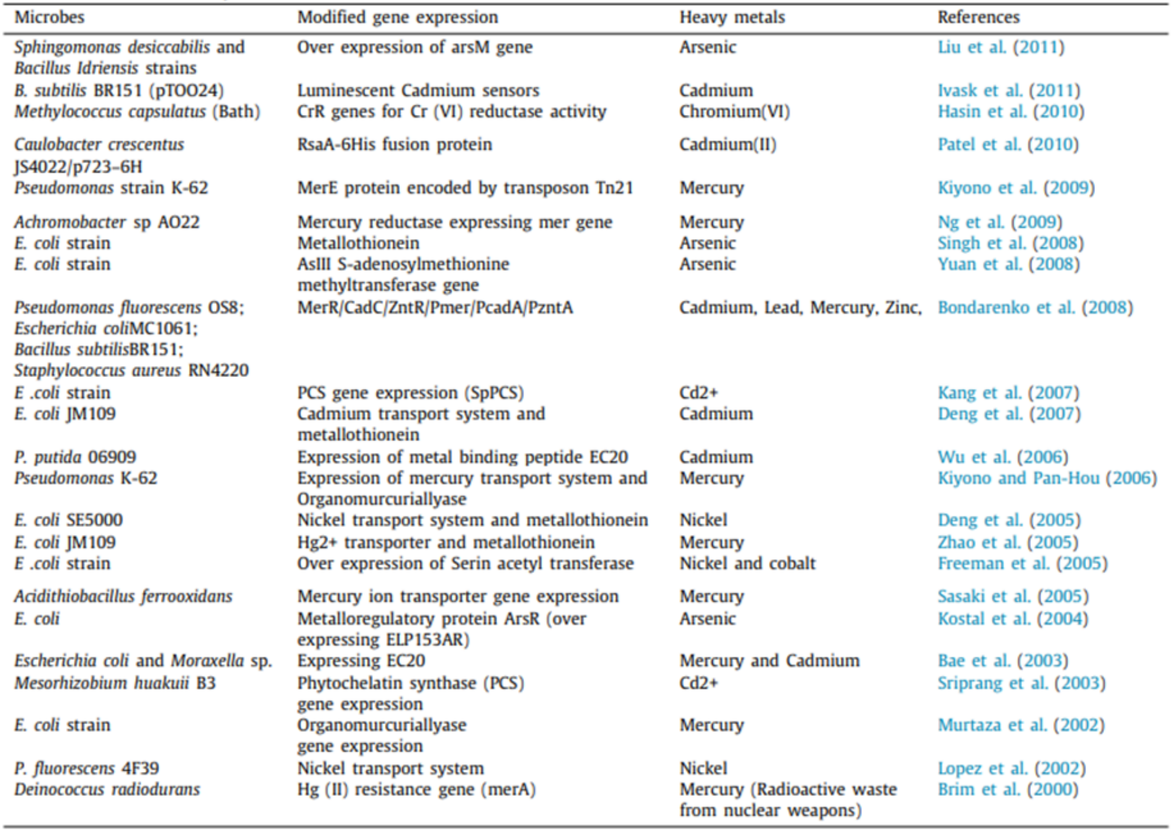
4.5Removal of heavy metals by biofilms

Effective bioremediation tools and biological stabilising agents include biofilm. Even at life-threatening levels, biofilms have an extremely high tolerance for potentially dangerous inorganic elements. In a research study. Metal removal effectiveness was found to range from 4.79 to 10.25% for planktonic cells and from 91.71 to 95.39% for biofilm cells. Exopolymeric compounds that are present in biofilms and comprise molecules with surfactant or emulsifier capabilities are two potential biofilm mechanisms of bioremediation [6, 10].

4.6 Genetic engineering for improved microbial remediation of heavy metal pollution

The generation and controlling of particular pathways, the engineering of bioprocesses for the clean-up and their observation and management, the development of specificity of enzymes and affinities, the advancement of bioprocesses for contaminants reduction, and the utilisation and potential uses of biological sensors in chemical-based sensing, toxic level reduction, and endpoint evaluation are the four primary techniques used to develop the GEM [5]. On the basis of these methods, genetically modified microbes have been developed to reduce the pollution caused by heavy metals. By changing certain genes, GEMs can be created [20].Through genetic engineering, microbe strains possess the capacity to eliminate a number of different forms of hydrocarbons. A Pseudomonas strain with several plasmids capable of oxidising terpenic, aliphatic, and polyaromatic hydrocarbons has been effectively developed. Recombinant DNA therapy, a type of genetic engineering that involves the interchange of genes between germs, may alter the genetic code of microbes. These microbes are referred to as genetically altered or genetically engineered organisms. It is well recognised that genetically modified organisms are efficient in groundwater, activated sludge, and soil bioremediation [26].

Table 7. Genetically modified organisms employed in the biological remediation of toxic metals [20]



Microbes	Modified gene expression	Heavy metals	References
Sphingomonas desiccabilis and *Bacillus Idriensis* strains	Over expression of arsM gene	Arsenic	Liu et al. (2011)
B. subtilis BR151 (pTOO24)	Luminescent Cadmium sensors	Cadmium	Ivask et al. (2011)
Methylococcus capsulatus (Bath)	CrR genes for Cr (VI) reductase activity	Chromium(VI)	Hasin et al. (2010)
Caulobacter crescentus JS4022/p723–6H	RsaA-6His fusion protein	Cadmium(II)	Patel et al. (2010)
Pseudomonas strain K-62	MerE protein encoded by transposon Tn21	Mercury	Kiyono et al. (2009)
Achromobacter sp AO22	Mercury reductase expressing mer gene	Mercury	Ng et al. (2009)
E. coli strain	Metallothionein	Arsenic	Singh et al. (2008)
E. coli strain	AsIII S-adenosylmethionine methyltransferase gene	Arsenic	Yuan et al. (2008)
Pseudomonas fluorescens OS8; *Escherichia coli*MC1061; *Bacillus subtilis*BR151; *Staphylococcus aureus* RN4220	MerR/CadC/ZntR/Pmer/PcadA/PzntA	Cadmium, Lead, Mercury, Zinc,	Bondarenko et al. (2008)
E .coli strain	PCS gene expression (SpPCS)	Cd2+	Kang et al. (2007)
E. coli JM109	Cadmium transport system and metallothionein	Cadmium	Deng et al. (2007)
P. putida 06909	Expression of metal binding peptide EC20	Cadmium	Wu et al. (2006)
Pseudomonas K-62	Expression of mercury transport system and Organomurcuriallyase	Mercury	Kiyono and Pan-Hou (2006)
E. coli SE5000	Nickel transport system and metallothionein	Nickel	Deng et al. (2005)
E. coli JM109	Hg2+ transporter and metallothionein	Mercury	Zhao et al. (2005)
E .coli strain	Over expression of Serin acetyl transferase	Nickel and cobalt	Freeman et al. (2005)
Acidithiobacillus ferrooxidans	Mercury ion transporter gene expression	Mercury	Sasaki et al. (2005)
E. coli	Metalloregulatory protein ArsR (over expressing ELP153AR)	Arsenic	Kostal et al. (2004)
Escherichia coli and *Moraxella* sp.	Expressing EC20	Mercury and Cadmium	Bae et al. (2003)
Mesorhizobium huakuii B3	Phytochelatin synthase (PCS) gene expression	Cd2+	Sriprang et al. (2003)
E. coli strain	Organomurcuriallyase gene expression	Mercury	Murtaza et al. (2002)
P. fluorescens 4F39	Nickel transport system	Nickel	Lopez et al. (2002)
Deinococcus radiodurans	Hg (II) resistance gene (merA)	Mercury (Radioactive waste from nuclear weapons)	Brim et al. (2000)

5.Future Prospects

Microbe-based clean-up is a novel approach with great effectiveness, low operating expenses, excellent efficiency, and reduced contamination generation. It is frequently used to eliminate pollutants from the surroundings as well as for the absorption of harmful chemicals from insecticides, fertilisers, and effluent. When a few expenses are taken into account, the possible capabilities of enormous-scale use appear promising given all of the benefits provided by the microbiological process of bio sorption. The biological remediation involves screening, and choosing the right strains of microbes is essential. Research on the processes behind toxic metal bio sorption and bioaccumulation by microbes is on-going, and more accurate kinetic and equilibrium systems are being developed. Chemical modification approaches and integration with other heavy metal removal technologies are also recommended for promoting the usage of microalgae biomass for heavy metal elimination. Different bioremediation techniques exist and can successfully clean up polluted settings. Modern molecular techniques, including genomes, proteomics, metabolomics, and transcriptomics, have helped us better understand the recognition, functions, metabolism, and breakdown processes of microbes. The type and concentration of contaminants may affect the development and metabolic functions of contaminating microorganisms that naturally exist at contaminating sites. A few years later, we can use agro-industrial waste products, which consist of potassium, phosphorus, and nitrogen, as an important source of nutrients for an extremely infected location [22].Currently being studied as bioremediations on a lab or commercial scale are industrial and agricultural biomasses, such as bagasse from sugarcane, shells of coconuts, garbage, husks of rice, and yeast from used beer cans. Various bio sorbents have improved their bio sorption capacity after various chemical and physical modifications, but additional investigation is required until such bio sorbents can be employed economically in many fields. The biological remediation approach calls for the development of methodical, workable, long-term procedures that can be effectively changed for any kind of situation.

Participation is essential across all levels, particularly among researchers, consumers, governmental organisations, and businesses [13].

Conclusion

As a result of major heavy metal poisoning, both humans and the environment are suffering greatly. The most effective alternative methods for remediating water have been found to be biological remediation approaches, which not only remove heavy metals biologically but also replenish the area while sustaining the natural balance of the surrounding ecosystem. This is in contrast to the difficulty and length of time required by traditional procedures. In order to reduce contamination of the environment, this paper examines the significance of microbial communities in the treatment of wastewater and also discusses the importance of microbial compounds and enzymes in metal decontamination. Cellular pathways are capable of regulating the level of metal resistance in microbes. In most cases, the microbiological approach avoids the formation of excessive heavy metals and, as a result, the beginning of influence energy. Metals have also been found to be mobilised and immobilised in a variety of ways by microbe-assisted removal techniques. Simultaneous gene transfer and the introduction of mutated microbes might still be promising approaches for sustainable implementation. Additionally, using a biological technique, a modified procedure combining genetically modified bacteria with a specific toxic chemical could increase the effectiveness of bioremediation. To increase the rate of biodegradability, scientists are also experimenting with recombinant or genetically altered microbes. Unluckily, the engineered microorganisms only demonstrated their full capability in controlled (lab) environments, limiting their ability to effectively remove contaminants such as heavy metals from their surroundings. Our goal is to work on the sustainability of genetically engineered organisms under in situ circumstances in order to increase the decontamination rate of toxic metals from polluted areas.

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