Chapter

A Review on the Resistance and Accumulation of Heavy Metals by Different Microbial Strains

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Abstract

Heavy metals accumulated the earth crust and causes extreme pollution. Accumulation of rich concentrations of heavy metals in environments can cause various human diseases which risks health and high ecological issues. Mercury, arsenic, lead, silver, cadmium, chromium, etc. are some heavy metals harmful to organisms at even very low concentration. Heavy metal pollution is increasing day by day due to industrialization, urbanization, mining, volcanic eruptions, weathering of rocks, etc. Different microbial strains have developed very efficient and unique mechanisms for tolerating heavy metals in polluted sites with eco-friendly techniques. Heavy metals are group of metals with density more than 5 g/cm^3. Microorganisms are generally present in contaminated sites of heavy metals and they develop new strategies which are metabolism dependent or independent to tackle with the adverse effects of heavy metals. Bacteria, Algae, Fungi, Cyanobacteria uses in bioremediation technique and acts a biosorbent. Removal of heavy metal from contaminated sites using microbial strains is cheaper alternative. Mostly species involved in bioremediation include Enterobacter and *Pseudomonas* species and some of bacillus species too in bacteria. *Aspergillus* and *Penicillin* species used in heavy metal resistance in fungi. Various species of the brown algae and Cyanobacteria shows resistance in algae.

Keywords: heavy metal resistance, bioremediation, biosorption, bioleaching, plasmid

1. Introduction

Air, water and soil which are the essential elements of life are contaminated rapidly due to increasing population, urbanization, mining activities and industrialization [1]. Heavy metals toxicity is causing problem to humans, animals, aquatic animals, plants and even microbes too.

Various methods are introduced to remove the heavy metal pollution like chemical techniques such as chemical precipitation, oxidation or reduction method, electrochemical treatment. Physical techniques such as ion exchange, evaporation, filtration, membrane technology, reverse osmosis. Biological techniques like microorganisms such as bacteria, fungi, algae, cynobacteria, lichens, etc.

Heavy metals damage cell membranes, alter functioning of enzymes, inhibit protein synthesis, denature protein and damage the structure of DNA. Toxicity is mainly created by the dislocation of essential metals from their real binding sites or ligand interactions [2]. Bioremediation is cost-effective, safe and eco-friendly; can be virtually restored a result to the heavy metal pollution issue as it is natural process. Biological methods are best to control short term or long term environmental pollution. Various heavy metals are accumulated with the help of bacteria, fungi, cyanobacteria, lichens, etc. and helps in bioremediation and used as bioindicators. They are not harmful human heath as well as ecosystem. Such organisms are used for indication and controlling heavy metal pollution. Mostly genes encoded by heavy metal resistant bacteria are located on plasmids. Biosorption is environmentally safe and low cost methodology of removing metals from the ecosystem. Various analysis were observed throughout previous 5 decades provided quantity of data regarding differing kinds of biosorbents and their mechanism of absorption of heavy metal. Additional research is to explore new biosorbents from surroundings [3].

Since last few years, various physical and chemical methods are used to remove heavy metals but it is expensive, needs laboratory and inefficient. According to various studies bioremediation and biosorption techniques are much more beneficial, cheap, non-toxic, natural process.

Minimum inhibitory concentration (MIC) is the lowest concentration at which the isolate or antimicrobial agent is completely suppressed is recorded. Microorganisms correspond to heavy metals using various defense systems, such as exclusion, compartmentalization [4], complex formation and synthesis of binding proteins, such as metallothioneins [5].

Bioremediation strategies have been proposed as an attractive alternative owing to their low cost and high efficiency [6].

Different methods are used to study characterization of heavy metals on microbes by 16S RNA sequence, biodegradability test, siderophore assay, biochemical test, morphological test, antibiotic resistance, nucleotide sequencing, etc. Microbial pigmentation and enzymatic activities like catalase, gelatin hydrolysis, oxidase, nitrate reductase, were characteristics selected to examine their outcomes.

Bioremediation is of two types: in-situ bioremediation and ex-situ bioremediation. In-situ bioremediation process is mainly used due to its ability in decreasing disturbance of ecosystem at the heavy metal polluted sites whereas ex-situ bioremediation, it takes place inside bioreactors, bio-piles and land farming. In-situ bioremediation is much more efficient and eco-friendly (**Figure 1**).

Metal microbe interactions developed by microbial cells are bio-transformation, bio-leaching, bio-degradation, bio-mineralization, bio-adsorption and bio-accumulation in bioremediation method.

Biofilm used as efficient bioremediation tool and stabilization too. Even at harmful conditions, they show high resistance towards heavy metals. With the help of genetic engineering one can insert desired characters like ability to resist heavy metals, tolerate metal stress, etc. For example: engineered *Chlamydomonas reinhardtii* shows increased resistance to cadmium toxicity. *Corynebacterium glutamicum* was genetically modified using ars (operon) to accumulate arsenic polluted sites. Biofilm combines or work with biosorbent or any exopolymeric substance which consist of surfactants or emulsifier properties. The study was conducted on *Rhodotorula mucilaginosa* shows efficiency in heavy metal removal and develops 91.7–95.4% biofilm cells. Biosurfactants studied were surfactin, rhamnolipid and sophorolipid for removal of several heavy metals.

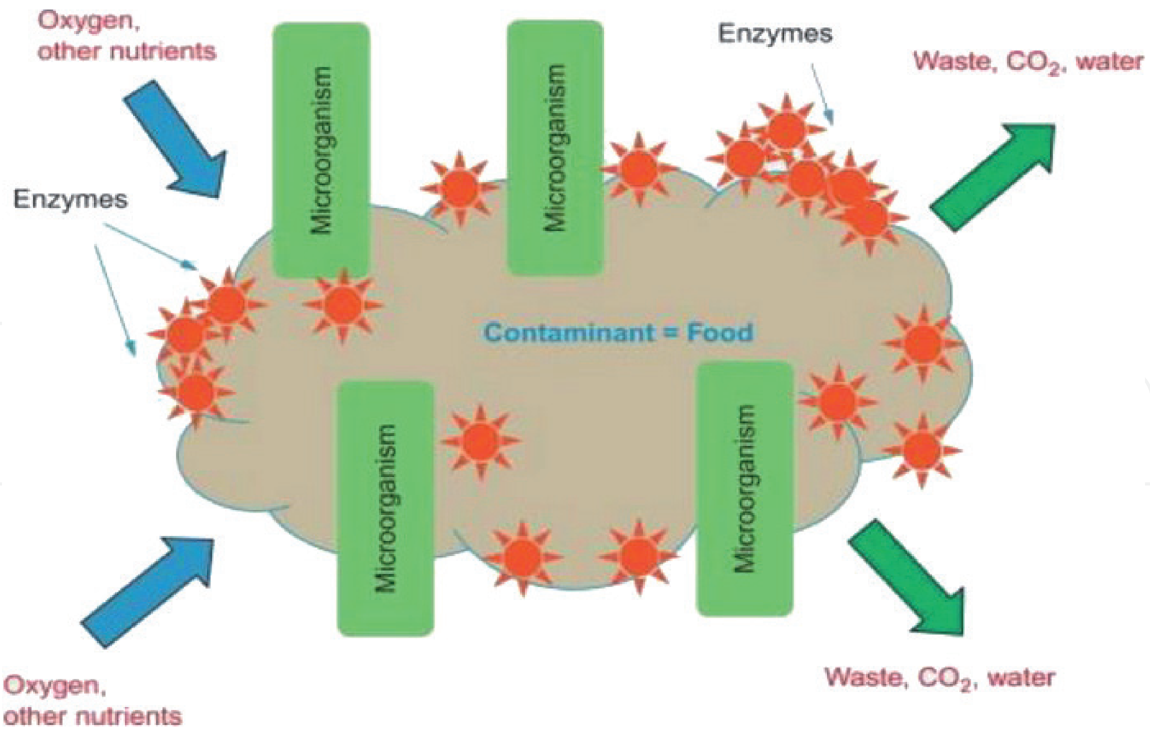

Figure 1.
Bioremediation (enzyme-catalyzed destruction) of contaminants. The use of power ultrasound in biofuel production, bioremediation and other applications [7].

The aim of the review is to study the source of the heavy metals on earth, consequences of the heavy metals on plants as well as on animals, various isolated microbial strains from bacteria, fungi and algae tolerance towards heavy metals and to study mechanism adapted by strain to accumulate heavy metals.

Future approaches in bioremediation are genetic modification of microbes or genetic engineered microbes, genetic technologies and forms specificity using biofilm by optimization process and immobilization process can be attained, biofilm mediated remediation, formation of microbial fuel cell (MFC), use of nano-particles with algae and bacteria, gene transfer within biofilm, transgenic cynobacteria, modify gene or enzyme in microbes. In Rhizo-remediation technique, *rhizosphere* bacteria and *mycorrhizae* combine for uptake.

2. Source of the heavy metals

High amount of heavy metals in the soil, water and air arise from various sources, which consist of natural sources include natural emission, atmospheric decomposition, sea salt spray, forest fires, rock weathering, biogenic means and wind borne soil particles and artificial sources such as mining activities, agricultural waste, domestic effluents, smelters, sewage sludge irrigation, improper stacking of the industrial solid waste, the excess utilization of pesticides, insecticides and fertilizers, etc. [8, 9].

2.1 Lead in environment

Lead (Pb) is unnecessary metal on the crust. It is a important contaminant that is present in the soil, water and air as a dangerous waste. It is extremely injurious to the human, animals, plants and even microbes too. The crucial sources of lead metal are children toys, drinking water, dust, petroleum, electronic industries, water pipes, battery, pottery, paint, stained glass, cosmetics and biocide preparation [10, 11].

2.2 Arsenic in environment

Arsenic (As) is non-essential metal. Arsenic is also present in pyrotechnics, in bronzing and hardening other metals. Arsenic is originated from the weathering of rocks and mineral, volcanic eruptions, fossil fuels, agricultural products, preservatives, medicinal products and industrial activities. Herbicides, pesticides, insecticides, fungicides and fertilizers also contribute to arsenic contamination and extremely deadly and carcinogenic [12] (**Figure 2**).

2.3 Mercury in environment

Natural activities like volcanoes and forest fire release mercury in environment. The burning of coal, oil, wood and mining of gold releases mercury in the environment. It affects immune system as well as nervous system. Methyl-mercury damages the developing embryos too [14, 15].

2.4 Chromium in environment

Chromium is released to environment by combustion processes and from metal industries and chemical manufacturing industries as waste. Chromium 4 is most dangerous form and may lead health issues like allergy, nose irritations, skin rashes, liver damage, kidney damage and even death [16, 17].

2.5 Cadmium in environment

Cadmium is also a non-essential member and highly dangerous to mankind. Cadmium is used in semiconductors, nickel-cadmium batteries, electroplating, municipal wastes such as plastics, PVC manufacturing, alloys, overuse of fertilizers rich in phosphate and control rod for nuclear reactors. Soils and water pollution by cadmium produced by the mining sites and smelting industries, sewage sludge

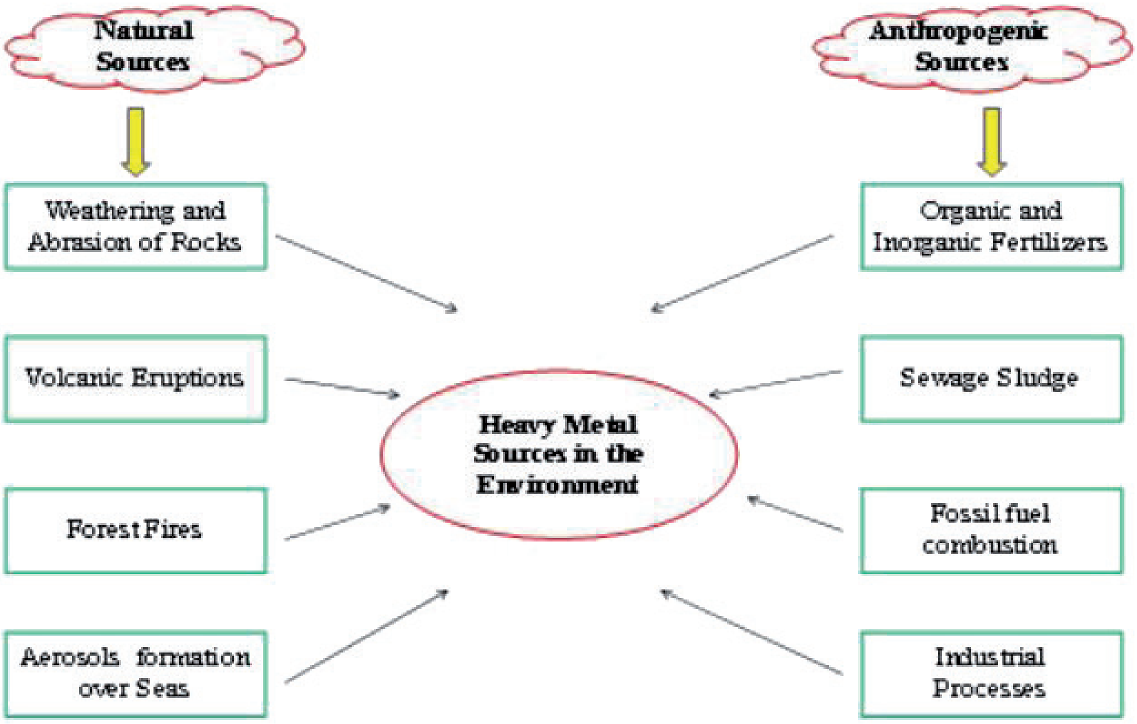

Figure 2.
Heavy metal sources in the environment [13].

application and burning of fossil fuels like coal, petroleum, etc. Chronic exposure of cadmium in human has many harmful effects such as high blood pressure and destroys to different organs such as lung, liver kidney and testes in males [18, 19].

2.6 Copper in environment

Copper a transition metal and also an essential element for living organisms including humans and other animals at low concentrations. Copper is released in ecosystem through decaying of vegetation, forest fire, sea-sprays, wind-blown dust. Copper is utilized as the alloy in the manufacture of wire, pipe, and various metal products. Copper are majorly used in agriculture to treat plant diseases, like mildew, or for water treatment and as preservatives, leather and fabrics. Intake of excessive amount of copper, it can cause nausea, vomiting, stomach cramps, diarrhea and can destroy liver and kidney and even lead to death [20, 21].

2.7 Zinc in environment

Zinc (Zn) is also a transition metal and zinc is utilized in galvanizing and alloying and also in the manufacture of electric goods, dying, insecticides, pesticides and cosmetics. Mining activities, smelting of metals and production of steel and other waste can release zinc into the environment. It may cause health issues in living organisms such as dehydration, nausea, electrolyte imbalance, vomiting, abdominal pain, dizziness, acute renal failure, muscular incardination and damage of hepatic parenchyma [22].

2.8 Manganese in environment

Manganese is released from sewage sludge, combustion of fossil fuels, mining processes, etc. it can cause toxicity in plants and causes swelling of cell walls, brown spots on leaves, etc. [23].

2.9 Iron in environment

The major sources of iron are metal refining, sewage, dust from iron mining, iron and steel industry. Iron sulphate is utilized in fertilizer and herbicide [24].

2.10 Other heavy metals in environment

Thallium is present in insecticides, metal alloys and fire cracker. Phosphorus is found in insecticides such as organophosphate for example: malathion [25].

The environmental factors plays very crucial role in biosorption of heavy metals and these factors are pH, temperature, biomass concentration, metal ion concentration. Algae, fungi and bacteria acts as biosorbents and helps in mechanism of biosorption [26].

3. Adverse effects of heavy metals

Heavy metal pollution is causing severe health effects in human body as well as animals and plants too. Heavy metals are also effected the growth of microbes which are used in treatment or accumulation of heavy metals by damaging their DNA. Heavy metals can cause skin allergies, cancer, effect major organs like kidney, liver, brain, lung, etc., and enter in blood stream and even death too in animals and humans. Retarded growth and development, bad shoot induction and root formation, less nutrient and mineral content and can even cause death in plants [27].

3.1 Adverse affects of heavy metals on humans

Heavy metals like lead, chromium, nickel, mercury, cadmium, arsenic, etc. may destroy and alter functioning of various prime organs such as the liver, lungs, kidney, brain, heart and even blood also. Heavy metal infectivity may be either quick (within few hours/days) or long term (within months). Prolonged exposure of few toxic heavy metals at even less concentration can cause cancer or even death too. Heavy metals may cause various severe health risk and diseases [28].

Heavy metals can affect human body by lead is carring to liver and kidney by red blood cells. Cadmium binds to blood cells, liver and kidney tissues. Arsenic is accumulated in blood, kidney, heart, muscle, lung liver and also in nails, hair, etc.

The effect of toxicity depends on the exposure route and chemical nature of particular heavy metal like lipid solubility, volatility, etc.

Some heavy metals like arsenic, lead, mercury, nickel, cadmium, etc. have carcinogenic effect. Some heavy metals like lead, manganese, etc. may induce neurotoxicity [29].

Heavy metals function as a pseudo element of the body while they can interrupt with metabolic processes. Few metals, like aluminum may be separated through excretory activities, and few metals get absorbed in the body and even in food chain, showing long term exposure. Heavy metal toxicity depends upon the absorbed amount, the path of exposure and time of exposure. This may lead to several health risks and can also result in huge loss due to oxidative stress induced by free radical formation [30].

Arsenic is most harmful heavy metal which is highly toxic and carcinogenic. It mainly affects endocrine system, lungs, kidney, pulmonary, nervous system and skin. It causes skin cancer, respiratory cancer, perforation of nasal septum, dermatomes, etc. ingestion in gastrointestinal tract results in vomiting, disturbance in circulation, damage nervous system and led to death. Other consequences are high blood pressure, heart attacks, decrease in production of blood cells, enlargement of liver, change in skin color, loss of sensation in limbs. Exposure of arsenic through air can cause lung cancer and bladder cancer [31].

Cadmium is another dangerous heavy metal and it targets renal region, bones, testes, cardiovascular, skeletal system and pulmonary organ. It causes proteinuria, glucosuria, osteomalacia, emphysemia, aminoaciduria, etc. It may damage kidney and lung [19].

Chromium damages the organ such as lungs, kidney, pancreas, testes, liver, pulmonary region of body. It causes problems like ulcer, perforation of nasal septum, respiratory track cancer [17].

Lead is also very toxic even in less amount and targets multiple organs such as spleen, bones, the nervous system, hemotopoietic system, cardiovascular, gastrointestinal, renal region and reproduction system too. It causes issues like anemia, central nervous system disorders, peripheral neuropathy, encephalopathy [32].

Manganese is required in small concentration in body but in excessive damages nervous system and led to central and peripheral neuropathies and brain damage [23].

Nickel damages pulmonary system and skin too. It results high chances of lung cancer, nose cancer, larynx cancer and prostate cancer and skin allergy or skin rashes. It also shows symptom like sickness, dizziness, birth defects, asthma, chronic bronchitis, lung embolism, heart disorders [19].

Zinc may cause nausea, vomiting, illness, anemia, stomach cramps, damage to nervous system and skin irritation. It causes skin allergy, dermatitis, brain disorder.

Increased amount of zinc effects pancreas, disturbs the metabolism of protein and amino acids in body and arteriosclerosis too [33].

Cobalt can cause vomiting, nausea, loss of appetite and may affect on lungs causing asthma, pneumonia and wheezing when exposed with cobalt metal and may develop various allergies or skin rashes. Mainly it is dangerous for heart muscle and causes heart muscle disease known as cardiomyopathy and shows rapid increase in count of red blood cells after long time exposure [34].

Copper damages liver, brain, cornea, lungs, immune system including blood cells. It causes gastrointestinal symptoms such as vomiting, nausea, abdominal pain and even lead to liver and kidney damage, genetic disorders, reproductive or developmental effects, delayed growth, prolonged bone formation and less body weights [35].

Tin effect both nervous system and pulmonary system. Exposure may lead to skin and eye irritation or respiratory tract problems. It causes pneumoconiosis, central nervous system disorders, visual defects, changes in EEG too [36]. Phosphorus symptom caused by exposure of phosphorus on human health includes sweating, headache, vomiting, abdominal cramps, weakness, ptosis, miosis, and severe issues are sensorimotor, polyneuropathy, atrophy and even led to respiratory paralysis [37].

The consequences of thallium exposure include blood vomiting, nausea, abdomen pain, eye disorder, mental retardation, hair loss and severe issues are cardiac failure, brain disorder and even coma too [25].

Mercury attacks the nervous system and renal region and may cause proteinuria. Inhalation of mercury may cause headache, memory loss, insomnia, tremors, neuromuscular and thyroid damage. It damages the chromosome structure and DNA. Effects on reproductive system by low sperm count, birth defects and even miscarriages too. During pregnancy, it may pass through placental barrier to embryo or baby for exposure [38].

The major organs targeted by these heavy metal mercury and lead causes neurotoxicity (brain), arsenic lead to hepatotoxicity (liver), cadmium causes nephrotoxicity (kidney)/pulmonotoxicity (lungs) and zinc mainly induce hematoxicity (blood).

The heavy metals interrupt in metabolic processes in two ways [39]:

- They are absorbed and thereby disturb role in major organs and glands such as the heart, liver, brain, kidneys, bone, etc.
- They displace the important nutritional minerals from their real place hindering their biological function. Consumption of foods, beverages, skin exposure, and the inhaled air are ways through which these contaminants can be present in body. It is unfeasible to reside in heavy metal free surrounding.

Various heavy metals produce ROS and damages DNA of the cell and disrupt reproduction cycle. Arsenic damages kidney and liver and may cause abdominal cramping, etc.

3.2 Adverse effects of heavy metals on marine animals

Heavy metals present in water by industrial effluent or agricultural waste like fertilizers, pesticides, etc. and deposited in water bodies and settle down and can present on surface with help of aquatic plants and aquatic macrophytes. Heavy metals stimulate the production of reactive oxygen species (ROS) that can damage aquatic organisms.

Several heavy metals accumulate in various major organs of the fish causing mortality. Firstly it affects the circulatory system by entering in blood and alters the components of blood. It makes the fish anemic and weak.

Huge amount of heavy metal shows inhibitory effects on the growth and development of aquatic organisms like fishes, phytoplankton and zooplankton. Heavy metals may cause disruption in respiration, damage respiratory track which leads to suffocation, reduces the sperm count, egg production and short life span. Heavy metals can disturb oxygen level, reduction of developmental growth or give rise to developmental anomalies, byssus formation and reproduction too. In juvenile phase shows high mortality and in adults decreased breeding ability. Heavy metal shows changes in structure and organs and may exhibit functional changes and transform metabolic pathways. Results of a research [40] showed that ten different fish species had the highest concentration of heavy metals is in liver and kidney.

The fishes like *Labeo rohita* and aquatic organism are eaten by humans as rich protein sources and heavy metal pollution may cause health risk in humans too through aquatic species. Cadmium can be bioaccumulated in mussels, oysters, shrimps, lobsters and fishes too.

Mercury in fish muscles occur as Methyl mercury which is formed in aquatic sediments. Movement of heavy metals in fish takes place through the blood where the ions are generally attached to proteins. There are five potential routes for the contaminants to enter an aquatic organism. The pathways are through the food, non-food particles, gills, the skin and oral consumption of water. Once the contaminants are accumulated, they are carried by the blood to the liver for modification and storage. If contaminants are altered by the liver, they can be stored or excreted in the bile produced in liver or reversed back into the blood stream for elimination by the gills or kidneys or stored in fat which is a hepatic tissue.

3.3 Adverse affects of heavy metals on plants

Plants require various heavy metals for their growth and excessive amount of heavy metals can damage cell structure, inhibition of major enzymes, inhibit the photosynthesis process and growth of plants, altered water balance, nutrient assimilation and can even cause plant death [41].

Heavy metal give rise to chlorosis, slow and poor plant growth, yield depression and even less nutrient absorption, disorders in plant metabolic processes and decreased potential to fixate molecular nitrogen in legumes of plants.

Seed germination was gradually retarded in the presence of large amount of lead. It can be due to long term incubation of the seeds and have resulted to compensate the toxic outcomes of lead by various mechanisms such as leaching, chelation, metal binding or absorption by microorganisms [42].

Replacing of major essential nutrients at cation exchange sites reveals indirect toxic effects on plant development. Enzyme metabolism is extremely crucial for growth and development of plants and heavy metals effect enzymes to inhibit many other major metabolisms in plants.

Heavy metals may lead to loss of fertility of soil by reduction in decomposition of organic matter by depletion of various microbes present inside the soil [43].

Copper is required as micronutrients in plants and helps in synthesis of ATP and assimilation of carbon dioxide. Excessive copper may exhibit oxidative stress and decreases growth of root.

Zinc required as micronutrient for synthesis of chlorophyll in plants. It retards growth of plants and nutrient level. It causes manganese and copper deficiency in shoot region.

Cadmium results in inhibition of growth and development, browning of roots tips and even death too.

Mercury can effects whole food chain and induces ROS and oxidative stress too. It causes depletion of germination in seeds, height of plant reduced flowering and fruit production, retarded growth and development.

Chromium induces the oxidative stress and degrades photosynthesis pigments in plants [30].

Lead degrades the development of roots and arsenic effects yield of crop and chlorosis, plant height and decreases ability of seed for germination [44].

Nickel is important and considered as macronutrient in plants but present in excessive amount can inhibit root growth, short shoot yield, etc. [45].

Enzymes and co-enzymes both are made up various elements such as cobalt. High concentration of cobalt may cause depletion in nutrients like proteins, amino acids, carbohydrates, etc. Also exhibit retarded plant growth and development.

Photosynthesis is prime phenomena in plants and it requires iron element. The excessive concentration of iron can inhibit photosynthesis itself [24].

Plants experience oxidative stress upon exposure to heavy metals that leads to cellular damage and disrupt of cellular ionic homeostasis. To decrease the detrimental outcomes of heavy metal exposure and their absorption, plants have participated in detoxification processes highly based on chelation and sub-cellular compartmentalization. A primary class of heavy metal chelator known in plants is phytochelatins (PCs), are produced by non-translation from reduced glutathione (GSH) in a transpeptidation reaction catalyzed by the enzyme phytochelatin synthase (PCS) [39].

The various biosorption techniques adopted by the plants such as phytoextraction, phytoextraction, rhizofiltration, phytovolatilisation and many others.

4. Bioremediation of heavy metals by microbial strains

Various microbial strains can accumulate the toxicity of heavy metals from bacteria, fungi, algae and helps in bioremediation and biosorption [46]. Bacterial strains show five different mechanisms in resistance to heavy metals. These mechanisms are by inhibiting the entrance of metals into the cell. The cell wall, membrane and capsule prohibit entry of metal ions inside the cellular body. Carbonyl group in polysaccharides of bacterial capsule accumulates the ions of heavy metals. Ions of metal like zinc, lead, and copper resulted resistance by *Pseudomonas aeruginous* biofilm [47].

In bacteria, active transport illustrate largest group of heavy metal resistance. Active transport remove metal ions from cell membrane and it can be placed on either on plasmid or on chromosomes [48, 49].

In intracellular sequestration, combination of metal ions to form large ion is done by several compounds inside cytoplasm of cell. Example; *P. putida* shows potential of intracellular sequestration of metal ions such as zinc, candium and copper [50].

In extracellular sequestration, metal ions are collected by periplasm or outer membrane of cells as insoluble compounds [51].

Condensation of metal ions was done by the bacterial strains. Strains decreasing chromate, vanadate and moyhybadate were observed from surroundings. Metal ions were utilized as electron donors for generating energy by bacterial isolates. Example: *S. aureus* strain for resistance of arsenic (As^{5+}/As^{3+}) [52], *Klebsiella pneumonia* for resistance of mercury (Hg^{2+}/Hg) [53].

4.1 Tolerance against heavy metals in bacteria

There are various processes of heavy metal resistance like extracellular barrier, extracellular sequestration, and active transport of metal ions (efflux), intracellular sequestration, and reduction of metal ions by microbial cells.

B. subtilis revealed the excessive potential to remove the amount of the cadmium.

Bacteria resistant to mercury are *Alcaligenes faecalis*, *Bacillus pumilus*, *Pseudomonas aeruginosa*, and *Brevibacterium iodinium* for the eradication of cadmium and lead metals.

59 isolated actinobacteria have shown resistance to the five heavy metals. Using molecular identification 16S rRNA, 27 strains were found to classified in the *Streptomyces* and *Amycolatopsis* genera [54].

Three strains were identified up to genus level based on their morphological, cultural, physiological and biochemical characteristics as *Gemella* sp., *Micrococcus* sp. and *Hafnia* sp. Among these three isolates, *Gemella* sp. and *Micrococcus* sp. exhibited the resistance towards lead, chromium and cadmium metals whereas *Hafnia* sp. exhibited reactivity to cadmium (Cd). All strains revealed dissimilar MICs against the heavy metals at different concentrations using Atomic Absorption Spectrophotometer [55].

Bacterial cell wall experiencing the metal ion is the primary constituent of biosorption. The metal ions get connected to the various functional groups such as (amine, carboxyl, hydroxyl, phosphate, sulfate, amines) exist on the cell wall of the microbe. The metal uptake mechanism involves binding of metal ions to reactive groups lies on cell wall followed by internalization of metal ions inside cell protoplast. Some metal in more amount are accumulated by Gram positive strains due to presence of glycoproteins in their cell wall. Fewer metal absorption by Gram negative strains is reported due to phospholipids and LPS in their cell wall.

4.1.1 Arsenic resistant bacteria

Gram positive and gram negative bacterial strains have been investigated in the absorption of heavy metals.

Arsenic resistant bacteria species are *Enterobacter* sp. and *Klebsiella pneumoniae* based on phylogenetic analysis of 16S rDNA sequence [56].

The *Enterobacter* sp. (MNZ1), *K. pneumoniae* 1 (MNZ4) and *Klebsiella pneumonia* 2 (MNZ6) species shows resistance towards arsenic and survive in the presence of high level of arsenic [57].

10 isolates of rhizobacteria out of which some were Gram-positive bacteria *Arthrobacter globiformis*, *Bacillus megaterium*, *Bacillus cereus*, *B. pumilus*, and *Staphylococcus lentus*), and few were Gram-negative bacteria (*Enterobacter asburiae* and *Rhizobium radiobacter*). *R. radiobacter* exhibited the highest MIC of greater than 1500 ppm of the arsenic metal [58].

Aeromonas, *Exiguobacterium*, *Acinetobacter*, *Bacillus* and *Pseudomonas* are isolates of bacteria that can tolerate high levels of arsenic species [59].

Acidithiobacillus, *Deinococcus, Bacillus*, *Desulfitobacterium* and *Pseudomonas* show resistance against arsenic [60] (**Table 1**).

4.1.2 Cadmium resistant bacteria

Cadmium resistant bacterium, *Salmonella enterica 43C* is isolated from industrial effluent was characterized on the basis of biochemical and 16S rRNA ribotyping [62].

S. no.	Microorganisms	Accumulation of heavy metals in ppm	References
1.	*Pseudomonas aeruginosa*	1596.6	[61]
2.	*Bervibacillius choshinensis*	1011.18	[61]
3.	*R.radiobacter*	1500	[58]

Table 1.
Arsenic removal by bacterial strains.

S. no.	Microorganism	Accumulation of heavy metals in ppm	References
1.	*Pseudomonas aeruginosa*	2200 mg/L	[64]
2.	*Alcaligenes eutrophus*	320 ppm	[65]
3.	*Staphylococcus xylosus*	278 mg/g	[66]
4.	*Rhodotorula* sp. Y11	11.38 mg/g	[67]

Table 2.
Removal of heavy metal by cadmium resistant bacteria.

The efflux processes involves cadA and cadB gene method, and encodes several efflux pump proteins and various functional groups like amine, carboxyl, phosphate and hydroxyl ease cadmium binding sites to bacterial surface such as chemisorption. The membrane impermeablility is regulated by enzymes used in detoxifying the cadmium metal [63]. Various processes on the basis of morphological, biochemical characteristics, 16S rDNA gene sequencing and phylogeny analysis exhibited that the strain RZCd1 was recognized as *Pseudomonas* sp. M3. In log phase, industrial strains revealed more than 70% of the cadmium accumulation [57] (**Table 2**).

4.1.3 Mercury resistant bacteria

With the help of 16S rRNA gene sequence, *Vibrio fluvialis CASKS5* strain was recognized. The mercury-absorption ability of *V. fluvialis* was examined at several amount of concentration and exhibit large MIC (Minimum Inhibitory Concentration) but low antibiotic resistance [68].

Staphylococcus, *Bacillus*, *Pseudomonas*, *Citrobacteria*, *Klebsiella*, and *Rhodococcus* are several species mainly used in bioremediation of mercury [69].

Highly mercury resistant bacteria strains were *Brevundimonas* sp. HgP1 and *Brevundimonas* sp. HgP2 with 16S rDNA from a gold mine situated in village Pongkor, West Java with high MIC of 575 ppm. The aim was to examine the effect of mercury on bacterial development and morphological changes of bacterial population. The development was observed by measuring optical density at 600 n [70].

Mercury-resistance in the bacteria isolates were classified into the various genera such as *Pseudomonas*, *Enterobacteriaceae*, *Proteus*, *Xanthomonas*, *Alteromona*, and *Aeromonas* [71].

Attachment to the cell membrane, influx and efflux adsorption, detoxification of toxic metals to less harmful form, the use of *metallothionein* protein were several processes for heavy metal resistance. Removal of the any ion can be decreased by efflux, an active extrution of the heavy-metal ion [72] (**Table 3**).

4.1.4 Lead resistant bacteria

Lead accumulation processes operated by the lead resistant bacteria isolates includes efflux mechanism, extracellular sequestration, biosorption, precipitation,

S. no.	Microorganism	Accumulation of heavy metals in ppm	References
1.	*Brevundimonas* sp.	575	[70]
2.	*Pseudomonas aeruginosa*	294.6	[61]
3.	*Bervibacillius choshinensis*	58.93	[61]

Table 3.
Removal of mercury by bacterial strains.

S. no.	Microorganism	Metal concentration in ppm	References
1.	*Pseudomonas aeruginosa*	625.8	[61]
2.	*Bervibacillius choshinensis*	625.8	[61]
3.	*Gemella* sp.	1350	[55]
4.	*Micrococcus* sp.	1100	[55]

Table 4.
Removal of Lead by bacterial strains.

alteration in cell morphology, enhanced siderophore production and intracellular lead bioaccumulation [73].

Four distinct bacteria were isolated with high levels of resistance to lead, each exhibited resistance to 2 mM lead on the minimal medium. Two were identified as Gram-positive genus *Corynebacterium* and two were the Gram-negative genus *Pseudomonas*. Three strains transferred no observable plasmid, indicating that the metal resistance is encoded by chromosomal [74] (**Table 4**).

Lead-resistant bacteria play an important role in the development of lead-exposed plants. The endophyte *Bacillus sp.* MN3-4 increases Pb(II) absorption in *Alnusfirma*, and *Pseudomonas fluorescens G10* and *Mycobacterium sp. G16* enhances plant development and growth and decreased Pb toxicity *in Brassica napus* [75].

4.1.5 Nickel resistant bacteria

The nickel-resistant bacteria were identified *as Shigella*, *Enterococci* and *Enterobacter*, but they were anaerobic, they only grew in the human samples from obese people and they tolerated a maximum concentration of 1 mM nickel [76].

Few strains *Cupriavidus sp.* ATHA3, *Klebsiellaoxytoca* ATHA6 and *Methylobacterium sp.* ATHA7 and their recognization was concluded on the basis of morphological, biochemical characteristics and 16SrDNA gene sequencing [77] (**Table 5**).

AIcaligenes eutrophus H16 and N9A strains and derivatives of strain CH34 lacking one or another of its natural metal resistance plasmid were used as recipients. Both of the plasmid, pTOM8 and pTOM9 of strain 31A conveyed resistance features which were expressed except *A. eutrophus* H16 [79].

S. no.	Microorganism	Metal concentration	References
1.	*Klebsiella oxytoca* strain ATHA6	83 mg/mL	[77]
2.	Enterobacter sp.	200 ppm	[78]

Table 5.
Removal of nickel by bacterial strains.

Nickel resistance isolates from bacteria isolated from New caledonia by DNA-DNA hybridization. The biotinylated probes of DNA were obtained from *Alcaligeneseutrophus CH34*, *Alcaligenes xylosoxidans 31A*, *Alcaligenes denitrificans 4a-2*, and *Klebsiella oxytoca CCUG 15788*. 9 probes were crossed with endonuclease-cleaved plasmid and all DNA samples from 56 nickel-resistant determinants. Few Caledonian isolates were recognized as *Acinetobacter*, *Pseudomonas mendocina*, *Comamonas*, *Hafniaalvei*, *Burkholderia*, *Arthrobacter aurescens*, and *Arthrobacter ramosus*isolates [80].

4.1.6 Copper resistant bacteria

Copper-resistant bacteria have been isolated from the different sources, but copper-resistant *Escherichia coli* strains were isolated from agricultural sewage and phytopathogenic *Pseudomonas* and *Xanthomonas* strains.

The *copA* gene was noticed in the copper resistant strains *Sphingomonas*, *Stenotrophomonas* and *Arthrobacter* isolated from the contaminated soil from agricultural fields [81] (**Table 6**).

Bacterial strains showed high level of removal of heavy metals, determinants like YJ3 and YJ7 maybe resistance to Cu and isolates like SWJ11, MT16, GZC24 and YAH27 may be resistance to heavy metals such as Cu, Pb, Cd, Ni and Zn. It has been observed that plant growth-promoting bacteria can enhance the development and heavy metal uptake of plants [83, 84].

Numerous bacterial species show resistance to heavy metal such as thallium, tungsten, uranium, plutonium, have been observed from sediment and water sample. *Pseudomonas aeruginosa* strains results in accumulation and resistance to these heavy metals. Plutonium is harmful for soil microorganism even at very low concentration and stops the growth of bacteria fungi present in soil and affects soil respiration [85].

4.2 Tolerance against heavy metals in fungi

Fungi are ubiquitous in nature and found in water and soil. Recent strains isolated from contaminated sites have shown exceptional potential to tolerate heavy metals [86].

Fungi show potential as biocatalysts to accumulate heavy metals and convert them into very less toxic metals. Fungi mostly use chelation method to upgrade the tolerance to harmful heavy metals.

Recent studies have concluded many fungal strains like Rhizopus *stolonifer* in tolerance to lead, cadmium, copper and zinc. *Pleurotus ostreatus* in strain is used in nickel resistance. *Aspergillus niger* lead to the removal of lead, zinc, iron by bioleaching process and *Aspergillus niger* lead to removal of Zinc, nickel, lead, cadmium, manganese by immobilized cells [87].

Fungus as biosorbents used in removal of heavy metal ions. Bioleaching involves use of heterotrophic fungi and their metabolic products for accumulation of heavy

S. no.	Microorganisms	Meta concentration in mg/L	References
1.	*Bacillus pumilus*	121.82	[82]
2.	*Staphylococcus pasteuri*	80	[82]
3.	*Agrobacterium tumefaciens*, strain CCNWRS33-2	300	[82]

Table 6.
Removal of copper by bacterial strains.

metals from solid waste. Bioleaching is alternative method to traditional methods and fungal strains such as *Aspergillus* and *Penicillin* are used. Micro colonial fungi (MCF) can be used as a aspect of future research in bioremediation field.

Fungi show two mechanisms for heavy metal tolerance:

a. Extracellular sequestration.

b. Intracellular sequestration.

Extracellular mechanism inhibits metal ions to entrance and intracellular mechanism decrease metal ions inside the cytosol. In extracellular system, fungal cells excrete the organic compound that does not belong to cell wall compounds to chelate metal ions.

In intercellular system, metal transport proteins show resistant by ejection of metal ions from inside the cytosol [88].

Fungi strains to tolerate heavy metals are *Aspergillus foetidus and Penicillin simplicissimum*.

4.2.1 Cadmium resistant fungi

Aspergillus versicolor, *Aspergillus fumigatus*, *Microsporum species*, *Cladosporium species*, *Paecilomyces species*, *Terichoderma* were investigated by results of Fazli et al. [89]. Biological mechanism of fungal isolate directly relies on resistance against cadmium metal. *Paecilomyces species* could accumulate 400 mg/L concentration of cadmium which is the highest MIC standard observed yet. Highly versatile fungus to cadmium stress was *Aspergillus versicolor* and most sensitive fungus species for inhibition of mycelia growth are *Microsporum species* and *Cladosporium s*pecies. Unique and advance technologies in bio treatment of heavy metals are metal uptake technique natively, utilizing combination of isolates and cell structures manipulation by autoclaving [90] (**Table 7**).

4.2.2 Lead resistant fungi

Penicillin oxalicumis species acts as a biosorbent and removes lead from aqueous solution. The isolates reveals uptake ability and tolerance to lead are *Aspergillus fumigatus*, *Penicllum simplicissimum* etc. Fungus biomass which is physically and chemically retreated again was a technique applied for biosorption of lead metal [94] (**Table 8**).

S. no.	Microorganism	Accumulation of heavy metals in ppm	Reference
1.	*Pencillium notatum*	500	[91]
2.	*Saccharmyces serviciae*	500	[91]
3.	*Penicillium verrucosum*	400	[91]
4.	*Penicillumfuniculosum*	500	[91]
5.	*Aspergillus niger*	400	[92]
6.	*T. ghaneuse*	1000	[55]
7.	*R. micosporus*	100	[55]
8.	*Trichodermabervicompactum QYCD-6*	150–200	[93]

Table 7.
Metal concentration of cadmium used in studying metal resistance in fungi.

S. no.	Microorganism	Accumulation of heavy metals in ppm	References
1.	*Aspergillus niger*	2000	[92]
2.	*F. meliae*	400	[55]
3.	*T. ghaneuse*	400	[55]
4.	*R. micosporus*	800	[55]
5.	*Pencilliumnotatum*	800	[91]
6.	*Saccharmyces serviciae*	700	[91]
7.	*Penicillium verrucosum*	700	[91]
8.	*Penicillum funiculosum*	800	[91]
9.	Trichodermabervicompactum QYCD-6	1600	[93]

Table 8.
Metal concentration of Lead used in studying metal resistance in fungi.

4.2.3 Mercury resistant fungi

Aspergillus niger and *Aspergillus flavus* used in bioremediation process in mercury contaminated soil. Both belongs to phylum Ascomycota and are soil fungi [95].

Fungal sensitivity against heavy metals alters the origination of fungal spores. Sporulation is a natural response created by fungi as metal avoidance strategy in heavy metal contaminated sites.

Formation of Metallothionein polypeptides reduce cytotoxicity and metabolize heavy metals in fungi. [96] (**Table 9**).

4.2.4 Nickel resistant fungi

Various fungi species such as *Aspergillus niger*, *Aspergillus giganteus*, *Penicillin vermiculatum*, *Gliocladium species*, *Beauvaria species*, *Trichodermaviride* and *Rhizopusstolonifera induces* shows sporulation due to increase in concentration of nickel in contaminated sites. Environmental factors like pH temperature organic matter and metal ions impacts toxicity of nickel. Alteration of magnesium transport minimizes nickel. Generation of chelating compounds like glutathione deactivates toxicity of nickel [97] (**Table 10**).

4.2.5 Arsenic resistant fungi

Bioaccumulation and biovolatilization through arsenic resistant species like *Penicillin sp*., *Aspergillus sp*., *Neosartorya sp*., *Gliocladiumreseum* and the yeast *Candida humicola* in removal of arsenic have been studied [98–101].

Microbes involved in biochemical mechanisms to exploit arsenic oxy-anions either as an electron acceptor (arsenate) for anaerobic respiration or as an electron donor (arsenite) to support chemoautotrophic fixation of carbon dioxide into cell carbon [102].

S. no.	Microorganism	Accumulation of heavy metals in ppm	Reference
1.	*Aspergillus niger*	2000	[92]

Table 9.
Metal concentration of mercury used in metal resistance in fungi.

S. no.	Microorganism	Accumulation of heavy metals in ppm	References
1.	*Penicillum funiculosum*	400	[91]
2.	*Saccharmyces serviciae*	300	[91]
3.	*Penicillium verrucosum*	400	[91]
4.	*Pencillium notatum*	400	[91]
5.	*Aspergillus niger*	1000	[92]
6.	*Aspergillus foetidus*	500	[88]

Table 10.
Accumulation of nickel by fungal strains.

Two arsenic resistant fungi are *Fimetariella rabenhortii* and *Hormonema viticola* were isolated from contaminated soil. In fungi, Evaluation of plant growth promoting factors. Arsenic shows resistance by mediation of phosphate solubilization. *F. rabenhortii* and *H. viticola* had capacity to produce indole acetic acid and siderophores [103].

acrA biosensor strain is first fungal biosensor for arsenic detection. Using fungi as whole cell biosensors have various advantages [104].

A non-pathogenic strain *Aspergillus niger* is broadly used in Industrial applications. Presence of lead and zinc does not affect the fungal spore growth (**Table 11**).

4.2.6 Iron-resistant fungi

Iron is essential in low concentration but very harmful in high amount of concentration. The fungal strains useful in iron resistance are *Aspergillus niger* and *Aspergillus foetidus* and some *Penicillium species* too. Fungal strains have good ability for bio leaching process by interfering functional groups of enzymes [105] (**Table 12**).

4.2.7 Cobalt resistant fungi

Cobalt metal is found in state of cobaltite, linnaeite, smaltite, etc. Some fungal strains help in accumulation of cobalt are *Aspergillus niger*, *Aspergillus foetidus* and

S. no.	Microorganism	Accumulation of heavy metals in ppm	References
1.	*Aspergillus niger (arsenic III)*	1200	[92]
2.	*Aspergillus niger (arsenic IV)*	1000	[92]
3.	*T. ghaneuse*	800	[55]

Table 11.
Removal of arsenic by fungal strains.

S. no.	Microorganism	Metal concentration in ppm	References
1.	*Aspergillus niger*	2000	[88]
2.	*Aspergillus foetidus*	3500	[88]
3.	*Penicilium* sp.	8000	[88]
4.	*F.meliae*	800	[55]
5.	*T.ghaneuse*	500	[55]
6.	*R. micosporus*	800	[55]

Table 12.
Removal of Iron by fungal strains.

S. no.	Microorganisms	Metal concentration in ppm	References
1.	*Aspergillus niger*	1500	[88]
2.	*Aspergillus foetidus*	500	[88]
3.	*Penicillium* sp.	2500	[88]

Table 13.
Removal of cobalt by fungal strains.

Penicillium spp. The factors that improve the removal of cobalt were fungal biomass, incubation time, pH, temperature, concentration of metal ions [106] (**Table 13**).

4.3 Tolerance against heavy metals in algae

Metal detoxification or chelation is one more strategy defense for heavy metal resistance. Algae secrete chelating molecules in response to metal ions that successively bind to them resulting in the sequestration of complexed metals in cellular organelles. Most of the algae strains are rumored to accumulate elevated metal ion concentration in cellular organelles. Additionally, the appliance of this metal resistance in biogenesis of metal nano-particles and metal compound nano-particles has been investigated by [107].

Algae are aquatic plants which absence of true roots and stems. Even when less nutrition is provided still they can grow in large biomass. Large size, high sorption ability and no production of harmful components are responsible for good biosorbent material. Features required for binding algae surface to heavy metal ions are algae species, ionic charge of metal and chemical composition of metal ion solution. Amine, carboxyl, sulfate, phosphate, sulfhydryl, hydroxyl, imidazole groups are metal ion binding sites on algal surfaces [108].

Algae show various mechanism such as formation of proteins which binds with metals, changes in structure of cell membrane, complexation or elimination of ions. Heavy metals can be eliminated for contaminated sites by either living cells or dead cells by usage of inactive biomass. Mechanism of absorption of living cells is very much complex than intracellular uptake [109].

Two processes in algal biosorption are involved. 1. Ion exchange method where ions present on algal membrane Ca, Mg, K, Na. They are displaced by metal ions. 2. Complexation between metal ions and functional groups. The metal removal process of algae is similar to bacteria by bonding of metal ions with the membrane [110].

Cladophora species are best bio indicator and *scenedesmus species* results in stress tolerance and accumulation of heavy metal like copper and chromium. In brown algae, cell wall contains fucoidin and olginic acid which helps in accumulation of heavy metals too [111].

Three fresh water microalgal determinants *Phormidium ambiguum* (Cyanobacterium), *Pseudochlorococcum typicum* and *Scenedesmus quadricauda* var. *quadrispina* (Chlorophyta) were tried for resistance and absorption of mercury (Hg^{2+}), lead (Pb^{2+}) and cadmium (Cd^{2+}) in aqueous solution. Transmission electron microscopy (TEM) was examined to contemplate the connection between heavy metal ions and *P. typicum* cells. At ultrastructural level, electron thick layers were recognized on the algal cell membranes when exposed to Cd, Hg and Pb [110] (**Table 14**).

Bifurcaria bifurcate, *oocystis*, *Pithophora spp*., *Sargassum* sp., *Sagassumtenerrimum*, *Fucusvesiculosus (brown algae), Ascophyllumnodosum*are resistant to cadmium. *Pithophora* spp., *Sargassum* sp., *Spirogyra* sp., are resistant to chromium. *Calotropisprocera*, *Pithophora* spp., *Fucusvesiculosus* are species resistant

S. no.	Metal	Microrganism	Biosorption of metals	References
1.	Lead	*Ascophyllumnodosum*	370 mg/g	[112]
2.	Lead	*Nostoc* sp.	93.5 mg/g	[113]
3.	Lead	*Synechococcus* sp.	0.25 mg/g	[114]
4.	Lead	*Fucus vesiculosus*	370 mg/g	[112]
5.	Lead	Oedogonium sp.	145 mg/g	[113]
6.	Cadmium	*Chlorella* sp.	40 mg/g	[115]
7.	Cadmium	*Sargassum vulgare*	0.79 mmol/g	[116]
8.	Cadmium	*Sargassum natans*	135 mg/g	[117]
9.	Cadmium	*Chlorella sorokiniana*	43 mg/g	[118]
10.	Nickel	*Fucusvesiculosus*	40 mg/g	[112]
11.	Nickel	*Ascophyllum nodosum*	30 mg/g	[112]
12.	Nickel	*S. natans*	24.44 mg/g	[112]
13.	Zinc	*Cyanobium species*	0.125 mg/g	[114]
14.	Zinc	*Hydrodictyon reticulatum*	390 μg/g	[119]
15.	Zinc	*Rhizoclonium hieroglaphicum*	77.29 μg/g	[119]
16.	Zinc	*Fucus vesiculoses*	0.80 mmol/g	[112]
17.	Copper	*Cyanobium species*	0.212 mg/g	[114]
18.	Copper	*C. sorokiniana*	46.4 mg/g	[118]
19.	Copper	*Laminaria japonica*	1.59 mmol/g	[120]

Table 14.
Heavy metal shows biosorption potential in algal species.

to lead. *Cladophorafascicularis, Spirogyra hyaline, Sargassum sp.* are resistant to mercury metal and *Sargassum* sp., *Fucusvesiculosus*, *Ascophyllumnodosum* are resistant to nickel [121].

Red algae *Porphyra leucostica* was used to treatment heavy metal accumulation in wastewater and contaminated water sites by Ye et al. [122]. It was reported that this species are so efficient biosorbent.

Microalgae are also capable in utilizing the removal of heavy metals for water contaminated sites. Microalgae are unicellular organisms and also known as phytoplankton which are visible under microscope only and found in both fresh and marine water. Microalgae show positive responses in the resistance towards the heavy metals and convey better chances of bioremediation. Microalgae are also used as a bio-indicator to check or identify the effects of contaminants on ecosystem. Microalgae exhibit biosorption methods to accumulate heavy metals by showing extracellular mechanism and intracellular mechanism to deal with high toxic concentration. Microalgae mostly used to treat wastewater as it releases oxygen as a byproduct during process [123].

Bioremediation by Cynobacteria (Blue Green algae):

Cynobacteria is efficient tool for enhancing the productivity of crop, and plants, formation of bio fuel, rise in fertility of soil and bioremediation also. To explore multiple functional bioagents, genetically engineered cynobacteria should be introduced heavy metals like cadmium, lead, copper, cobalt, manganese were treated with different cynobacterial species such as *N. muscorum*, *A. subcylindrica*, *Nostoc*, *linckia*, *N. rivularis,* etc present in sewage and industrial waste water [124, 125].

Heavy metals develop oxidative stress by generation of reactive oxygen species (ROS) which is extremely toxic and damages the nucleic acid-DNA and RNA, protein and lipids also.

Cynobacteria acts as bioremediator because of their photoautotrophic nature and capability in nitrogen fixation. It is able to tertiary level of agro industrial effluents like oil refineries, paper and pharmaceutical industry. *Nostoc species* and *Microcystis species* accumulate wide range of organophosphate insecticides. As it is found in contaminated water sites and helps in high yield of plants and utilized for bioaccumulation. It can help to enhance the fertility of soil and useful as bio-fuels. It can be used as a good biofertilizers. Mechanism adopted by cynobacteria response to salanity result in bio-polymer production.

Cynobacteria develop bio-flocculants that shield there body mechanism from toxicity of heavy metas. Bio-flocculants are outlined by the presence of various negatively charged binding sides that permit cynobacteria in resistance of heavy metal from contaminated sites [126]. Cynobacteria have flourished numerous mechanisms for reducing the metal stress by intracellular metal sequestration, extracellular mechanism or binding of metals ions.

Metalithionein are metal binding proteins released by cynobacteria that support organism in metal sequestration of dangerous heavy metal ions.

Use of cynobacteria is much better than other microbes like bacteria fungi because of various other benefits like growth promoters, bio stabilizer, bio energy resource (bio-diesel), bio fertilizer, wasteland reclamation, carbon dioxide sequestration, methane oxidation.

Cynobacteria are very much efficient because of short generation time and helps in atmospheric nitrogen fixation.

Lichens in bioremediation:

Lichens are made by symbiotic association of fungi and algae in which both benefit each other. In wastewater remediation, lichens used as a biosorbents.

In heavy metal contamination, lichens can be used as bio-monitors too and the capability to accumulate heavy metal allows the monitoring ability. Lichen *Permelia perlata* shows the potential in biodegradation in contaminated sites.

Lichens adopt numerous processes for metal uptake such as extracellular uptake by ion exchange method intracellular removal and capturing of metal particles. The studies done by UK researchers on lichen results that lichen reproduces on land contaminated with uranium particles from mining activities and lichen converts uranium into dark particles. Endolithic lichen can be studied as a future approach in field of bioremediation [127].

5. Conclusion

Heavy metal pollution are very harmful for humans, animals, aquatic species and plants too and they were accumulated on earth crust by natural process as well as human activities such as industrialization, urbanization, mining and extraction, agricultural practices, etc. Bioremediation is the process which use either naturally occurring or deliberately introduced microorganisms to consume and break down environmental pollutants, in order to clean a polluted site. Various studies had been done and various strains were investigated are above mentioned. Bacteria, Fungi, Algae all are helpful in maintaining tolerance against heavy metals in different contaminated sites. There are several microbes present that provide heavy metal resistance through develop different method of resistance against different heavy metal. It can reduce heavy metals from environment to some extent. Further research area needs to be extended on the focus of gene transfer within bio-films for Bioremediation and use of genetic modified organisms. These strategies would facilitate the development of improved techniques for the bioremediation of heavy metals in the environment.

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Author contribution

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Conflict of interest

The authors declare that they have no conflict of interest in the publication.

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