Chapter 11
Physico Chemical and Biological Treatment Techniques for Lead Removal from Wastewater: A Review

Simmi Goel

Abstract The release of untreated industrial effluent loaded with heavy metals especially lead ions seems to have adverse effects on various components of ecosystem. A variety of physicochemical methods for the treatment of lead-contaminated water have been used on a commercial level. But these methods are having a lot of limitations like reduced efficiency, costly due to input of a load of chemicals and not environment friendly. In lieu of this, major focus is given on the use of biological methods especially biosorption for treatment of industrial effluent. In this review, various sources and health effects of lead-contaminated water has been given. A variety of physiochemical methods for the treatment of industrial wastewater and also limitations have been discussed. Significance of various biological methods over other conventional treatments including the use of agricultural waste, plant- or animal-based sorbents and enlisting the list of microbes like bacteria, fungi and algae as sorbents for treatment of lead waste water including their mechanism of action have been reviewed. The factors which need to be optimized for maximum removal of lead ions to increase the efficiency of treatment have also been discussed.

Keywords Lead contamination · Biosorption · Bioremediation · Biomass · Industrial effluent · Sorbents · Optimized parameters · Wastewater treatment

11.1 Introduction

A large number of electroplating industries discharge untreated wastewater into the ecosystem. The easy absorption of heavy metals in humans resulted due to their high dissolution capability in water. These heavy metals once released into environment their concentration increases with each trophic level resulted in bioaccumulation. Consumption of heavy metal–contaminated water beyond the permitted

S. Goel (✉)
Department of Biotechnology, Mata Gujri College, Fatehgarh Sahib, Punjab, India
e-mail: simmibiotech@matagujricollege.org

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level results in serious health disorders. The heavy metal–contaminated wastewater when discharged untreated in the environment resulted in the ecosystem degradation. The various manmade activities like batteries manufacturing, automobile industries, mining activities, leaching of ores, agricultural inputs in the form of chemicals are the major contributors of heavy metals into the ecosystem. These are difficult to degrade under natural conditions, altering the bio-geochemical cycles, disturbance of ecological diversity and ultimately destroying the whole ecosystem (Chug et al. 2022). Once these metals enter into the food chain, there occurs a huge concentration rise with each successive trophic level. The consumption of heavy metal–contaminated water causes kidney infections, respiratory dysfunction and cardiovascular imbalance and carcinogenic in acute cases. The industries release a large amount of heavy metal–loaded wastewater, among which lead (Pb) seems to be the major toxicity contributor released from metal finishing, electroplating and paint manufacturing, leaching, battery operations, etc. Lead once discharged persists into environment for a long period due to its non-biodegradable nature (Raut et al. 2015). Lead is discharged naturally from leaching of ores and also due to major human source like exhaust fumes of automobiles from where lead gets accumulated on the surface of road side vegetation or deposited within soil particles and ultimately through rain water enters into the rivers and ground water. Lead enters in human body through contaminated drinking water and accumulated in bones causing neurotoxicity and carcinogenicity (Biela and Sopikova 2017). Once lead is ingested in human body, it acts as metabolic poison resulted in inhibiting various enzymatic actions (Lo et al. 1999). In addition, the intake of lead-contaminated water can cause infections in kidneys, nervous breakdown and dysfunction of reproductive organs, heart, liver and brain (Naiyaa et al. 2009). In adults, lead poisoning can cause neurological disorders resulting in weakness, irritation, poor attention span, headaches, muscle cramps, memory loss and hallucinations and ultimately death. Lead ions (Pb^{2+}) can cause mental retardation, kidney damage, anaemia, central nervous system dysfunction, alters haemoglobin production, reproductive failure and gastrointestinal tract infections. The lead particles released in atmosphere get deposited on the surface of fruits, vegetables, soil and groundwater adversely affecting the health of especially the pregnant women and young children (Ghosal et al. 2021). In lieu of all these facts, there seems to be an urgent need to develop effective treatment technologies for the removal of Pb from water and wastewater to keep the safety and protection of human health and environment.

11.2 Sources of Lead

Major sources of lead are acid battery manufacturing, metal plating and finishing, mining operations, battery services, ammunition, tanneries, petroleum refining, tetraethyl lead manufacturing, paint industries, use of heavy metal–loaded chemicals in agricultural fields, pigment manufacture, coal combustion power plants, ceramic and glass usage, printing and photographic activities, lead water pipes (Goel et al.

2005; Momcilovic et al. 2011). Other contributors of lead used to be the exhaust gases of automobiles, which ultimately accumulate on the surface of crops growing alongside roads, entering the food chain, retained in water droplets in atmosphere and released in form of rains leading to the contamination of surface water and groundwater bodies. The surface and groundwater lead contamination also occurs due to the accidental leakages from rusting of the water pipes and waste water from the ferrous metallurgy operations, batteries discharge and glass manufacturing industry (Pitter 2009; Biela and Sopikova 2017).

11.3 Effects of Lead Exposure

The consumption of lead-contaminated water can severely affect the functioning of kidneys, liver, brain, nervous disorders, reproductive failure, hypertension ultimately leading to illness or death of individuals. Fatal exposure to lead-loaded wastewater can cause reproductive failures and foetus loss resulting in abortions. Exposure to lead ions (Pb^{2+}) can also cause mental retardation, kidney failure, anaemia, retards the functioning of central nervous system, haemoglobin production, reproductive failure and gastrointestinal infections. Lead particles released in air contaminate the agricultural food by depositing on surface of fruits, vegetables, soil and water. Other health effects of lead exposure are uneasiness, irritable behaviour, loss of focus/ concentration, migraines, muscular tremors, abdominal cramps, infections in kidney, hallucinations and memory loss. (WHO 2011; Biela and Sopikova 2017). Some of essential ions can be displaced or substituted from their cellular locations resulting in retardation of functioning of enzyme, polynucleotides and essential nutrient transport systems due to consumption of mercury and lead-contaminated water. Additionally, these also resulted in the denaturation and inactivation of enzymes and alters the integrity of cellular and organelle membranes (Zhang et al. 2016). In lieu of all these adverse effects, a very minute concentration of lead in drinking water seems to be highly toxic and so there is a strong need for developing an efficient removal, environment friendly and economical treatment technology (Mahmoud et al. 2012; Ghosal et al. 2021).

Atmospheric lead particles get deposited on vegetation and absorbed within aquatic organisms (Jamali et al. 2009), finds its way to enter the human body through the food chain. The lead contaminated soil alters the physiological, morphological and biochemical characteristics of plants by making their availability in the roots, stems, leaves and fruits through contaminated soil. Other severe threats of exposure to lead resulted in carcinogenesis, teratogenesis and gene mutations in humans (Wendt and Lee 2010). All these threats diverted the attention of scientists and researchers to explore effective and economical methods to remediate lead (Pb) pollution from wastewater (Jing et al. 2021a, b).

The intake of lead (Pb) through contaminated fruits, vegetables, water etc., causes anaemia, renal infections, nervous breakdown and ultimately death. Excessive intake leads to hepatic and renal failure, respiratory infections, reproductive disorders, capillary damage, gastrointestinal irritation and central nervous system irritation, nausea, encephalopathy, severe migraine and vomiting, learning disability, mental disorders, hyperactive behaviour, muscular tremors, liver cirrhosis, dysfunction of thyroid gland, sleep disorders, weakness, schizophrenia (Kale et al. 2018). Heavy metal intake can cause allergies, carcinogenic, organ damage, impairs growth and development due to their persistent or non-biodegradable nature. Overall lead poisoning can cause anaemic behaviour, kidney disorder, brain disorder and even death in extreme poisoning situation (Acharya et al. 2013; Singha and Das 2015). According to WHO, the acceptable safe limit of lead in drinking water is 0.01 g/L.

11.4 Methods for the Removal of Lead from Wastewater

The common modes for the removal of lead (Pb) from contaminated wastewater include physical methods such as ultra-filtration, coagulation, flocculation, adsorption, membrane filtration, floatation, reverse osmosis and ion exchange and chemical methods include neutralization, solvent extraction, chemical precipitation and electrochemical treatment.

Among these methods, adsorption seems to be highly effective and economical mode. The commonly used adsorbents for wastewater treatment are silica gels, activated alumina, metal oxides and hydroxides, zeolites, clay minerals, synthetic polymers, and carbonaceous materials, such as activated carbon and molecular carbon sieves.

11.4.1 Adsorption

The adsorption capacity of hydroxyapatite nanorods and chitosan nanocomposite was assessed for the removal of lead ions from aqueous solution in a batch mode of experimentation (Mohammad et al. 2015).

11.4.2 Chemical Precipitation

Chemical precipitation is based on the reaction of heavy metals with added chemicals resulting in the formation of insoluble precipitates in the form of hydroxides, sulphides, carbonates which can further separated by filtration. Addition of caustic soda increases the precipitation of dissolved lead (Pb) from wastewater in the form of solid metal hydroxide particles. Various coagulants and flocculants are added to increase their particle size so that these can be easily removed in the form of sludge. The precipitates can be further separated using sedimentation or filtration techniques.

Various parameters which need to be optimized for increasing the efficacy of lead removal are low pH, temperature, content of lead ions, contact time, presence of other ions and charge of ions (Ahluwalia and Goyal 2007).

11.4.3 Ion Exchange

This method is based on the ion exchange capacity of various cations or anions like zeolites or resins to remove the metal ions in the solution. The method is based on the concept of attracting soluble ions from the liquid phase and their transition to the solid phase, commonly used method in water treatment industry.

Ion exchange resins have the property of absorbing cations or anions from an electrolyte solution and release other ions with the same charges into the solution in an equivalent amount. Strong acid cation or weak acid cation or anion resins are used for lead removal. For example, the positively charged ions in cationic resins such as hydrogen and sodium ions are exchanged with positively charged ions, such as nickel, copper, zinc, copper, silver, cadmium, gold, mercury, lead, chromium, iron, tin, arsenic, selenium, molybdenum, cobalt, manganese and aluminium ions in the solutions. The negative ions in the resins such as hydroxyl and chloride ions can be replaced by the negatively charged ions such as chromate, sulphate, nitrate, cyanide and dissolved organic carbon.

11.4.4 Coagulation–Flocculation

This process is based on the capacity of the electrostatic bonding between heavy metal and coagulant–flocculants agents to form multi-charged polynuclear complexes. The commonly used metal coagulants to hydrolyse the metal ions are aluminium sulphate, aluminium chloride, ferric sulphate, ferrous sulphate, ferric chloride, hydrated lime and magnesium carbonate. Various flocculating agents are added to the wastewater to increase the particle size. These flocculated large sized particles can be easily removed by filtration, straining or floatation. Naturally occurring cactus juice can be effectively used as a bio-flocculant to reduce chromium concentration in wastewater.

11.4.5 Membrane Separation

The method depends on the efficacy of permeable barriers to remove contaminants by passing wastewater through porous membranes under pressure. The variations in the pore size of membranes allow certain particles to easily pass through while retaining others based on principle of size exclusion. The commonly used membrane separation techniques like ultra-filtration, nano-filtration and reverse osmosis can be utilized for heavy metal removal from wastewater (Chaemiso and Nefo 2019).

11.4.6 Ultra-Filtration

This method is based on the efficiency of membrane permeability to separate heavy metals, macromolecules and suspended solids from wastewater on the basis of the pore dimensions and molecular weight of the impurities. Various water-soluble polymers can be added which can bind metal ions resulting in the formation of macromolecular complexes by producing metal ions free effluent. An integrated and hybrid approach of using metal-binding polymers in combination with ultra-filtration to remove heavy metals from aqueous solution was investigated by various researchers (Qasem et al. 2021).

11.4.7 Reverse Osmosis

The method of reverse osmosis is based on the concept of applying forced pressure to solution resulted in the retaining of the solute particles and allows the pure solvent to pass through the membrane. The type of membrane in reverse osmosis is semipermeable in behaviour. It allows the selective passage of pure solvent but not for metals, i.e. solute particles. The semipermeable membranes used for reverse osmosis have a dense barrier layer in the polymer matrix where most of the separation occurs.

11.4.8 Electrodialysis

The method of electrodialysis involves the passage of various ionic species through ion exchange semipermeable membrane under the action of electric potential. The membranes are made of thin sheets of plastic and selective for either positively charged or negatively charged ions. Anions move towards anode and cations move towards cathode. One of the modifications of this is cation-selective membranes with negatively charged matter, which rejects negatively charged ions and allows positively charged ions to flow through. Selective membranes are fitted between the electrodes in electrolytic cells and under continuous electrical current, the associated ion migrates, allowing the recovery of lead ions (Qasem et al. 2021). Various factors like flow rate of ions, voltage and temperature affect the efficiency of removal.

11.4.9 Electro-Coagulation

This method is based on the use of electrical current to remove suspended solids, tannins, dyes and dissolved metals especially lead ions from wastewater. When these ions and other charged particles are neutralized with ions of opposite electrical charges provided by electro-coagulation system, they become destabilized and precipitated in a stable form (Arbabi et al. 2015; Hunsom et al. 2005; Rahman et al. 2015).

Factors need to be controlled for maximum removal of lead ions:

i. content of lead in effluent, acidic or alkaline conditions, temperature, flow rate.
ii. Organic and inorganic load of effluent.
iii. Cost investment and the maximum permissible limits as set by government agencies.

Limitations: These physicochemical methods are not cost-effective and possess certain disadvantages like sludge production, low metal ions removal efficiency, energy consumption and low selectivity which limits their usage especially in small-scale industrial treatment plants. Moreover, these techniques are too expensive on large scale or commercial level and also dangerous for constant monitoring as these cannot completely treat the wastewater (Siddiquee et al. 2015; Tarekegn et al. 2020).

Physicochemical methods used for the removal of heavy metal ions from wastewater are often ineffective if the concentration of heavy metals is very low. The heavy metals present in dissolved form in wastewater cannot be separated using physical methods. The methods for heavy metal removal like chemical precipitation, chemical oxidation, ion exchange, membrane separation, reverse osmosis, electro dialysis are not very effective, non-economical and require high energy input. These are also associated with generation of toxic sludge, disposal of which makes it expensive and non-eco-friendly in nature (Kale et al. 2018).

11.5 Biological Methods for Lead Removal from Wastewater

In view of all these facts, sorption seems to be an effective and economical method for the removal of heavy metals especially lead from wastewater (Kale et al. 2018). The sorbents used for the removal of pollutants can be of chemical or biological origin. Out of these biological sorbents like viable or non-viable microbes or plant- or animal-based products proved to be an attractive alternative over the chemical sorbents due to their better efficacy, easy availability, economical and pollution-free approach (Table 11.1). The technique of using biological originated sorbents for the removal of pollutants is known to be biosorption or bioremediation (Fig. 11.1).

The various features of biosorption including low capital investment, metal specificity, increased efficiency, no sludge generation, no need of chemical additives,

Table 11.1 List of various biosorbents for lead removal from wastewater

List of biological sorbents	Examples
Agricultural sorbents	Rice husk, saw dust, peanut husk, wheat bran, groundnut husk, banana pith, cork powder, corncob, coir pith, sugar beet pulp, hazelnut shell, jackfruit, maize cob or husk, rice straw, coconut shell, sawdust of walnut tree, almond hulls, sugarcane bagasse, maize husks, shea butter seed husks, coconut fibre, sugar beet pulp, nut shells
Sludge sorbent	Activated sludge, sewage sludge, alum sludge
Plant-based sorbent	Stem, leaves, roots, vegetable and fruit peels, Pomegranate peel, cork, bark, sunflower stalk, tree sawdust, seaweeds, lichen, pine barks, tea leaves, plant tissues, date stones, grape fruit peel, peat and nut shells, coconut shells, rice husk, tea waste, peanut hulls, almond shells, peach stones, citrus peels
Animal-based sorbent	Egg shells, shells from aquatic animals

Source (Shartooh et al. 2014; Reddad et al. 2002; Saeed et al. 2005; Chockalingam and Subramanian 2006; Montanher et al. 2005; Khan et al. 2004; Lu et al. 2008; Husoon 2011; Kale et al. 2018; Chowdhary et al. 2022)

recovery of biosorbent and metal make it highly reliable and effective mode of treatment (Volesky 1994). The usage of crop and forest waste including agricultural wastes as sorbents not only allows for sustainable waste utilization, but also helps to remove toxic heavy metal ions from wastewater (Liu et al. 2018; Jin et al. 2020; Zhang et al. 2021). The use of waste biomass materials, including cotton stalks and grapefruit peels (Trakal et al. 2014; Fu et al. 2021; Shartooh et al. 2014), as precursors to process various activated carbon adsorbents to remove toxic heavy metals from wastewater is an active area of research.

11.5.1 Mechanism of Biosorption

The mechanism of sorption of heavy metal ions using microbes includes two pathways. First is the initial passive and rapid uptake which occurs via surface adsorption on the cell wall components and polysaccharides. Second is the further active and slow uptake which occurs through the membrane transporting metal ions within the cells.

Various mechanisms involved in the process of biosorption are as follows:

- Toxic states of heavy metals can be transformed into non-toxic states by alkylation or various redox reactions. The availability of metals depends upon the dissolution capacity and movement which further depends on their valency and anionic or cationic form of metals. For example, hexavalent form of chromium is more toxic and hazardous than its trivalent form.

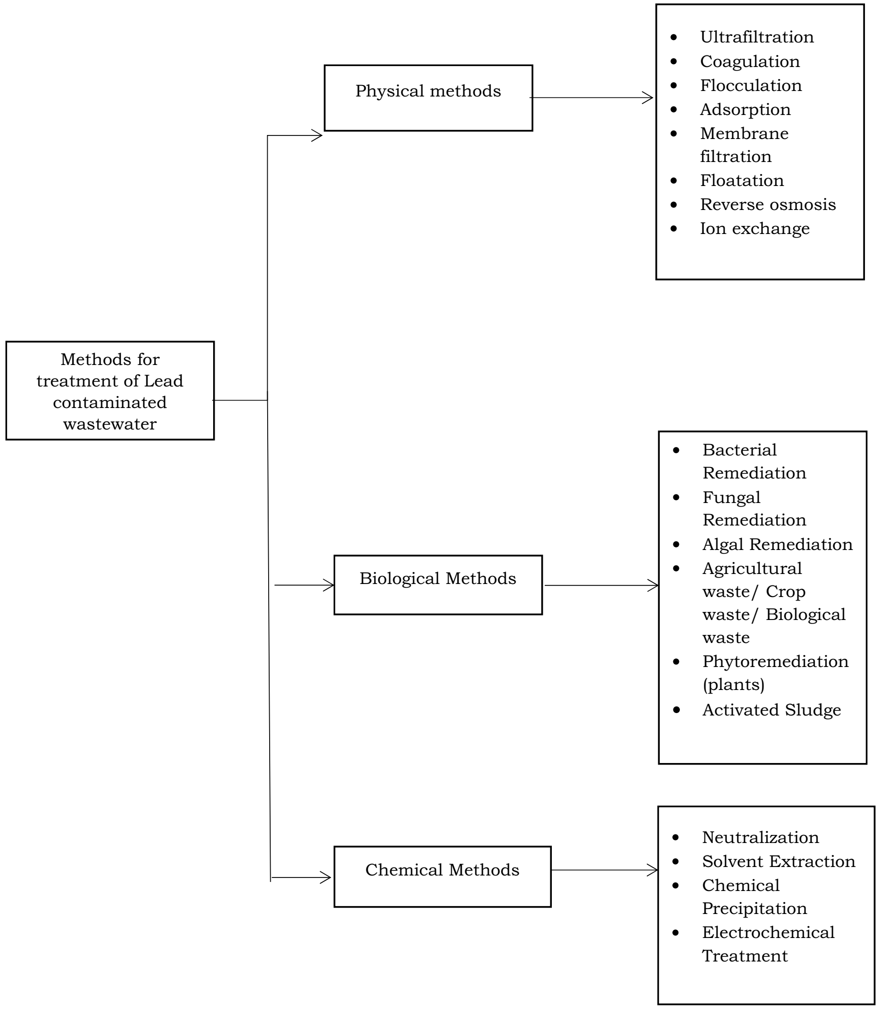

Fig. 11.1 Flowchart enlisting various methods for the removal of lead from wastewater

- Passive sorption is metabolism-free process, in which metals bind to functional groups present on the cell surface through electrostatic attraction, precipitation, surface complexation, ion exchange and physical adsorption. The factors including temperature, ionic strength, concentration and type of the sorbate and sorbent, state of biomass: suspension or immobilized and the presence of other anion and cations in the growth medium controls the efficacy of the removal of metal ions from wastewater.

- Active sorption is the metabolism-dependent intracellular uptake of heavy metals within the living cells within cytoplasm. Heavy metals are removed from wastewater by binding with metal-binding proteins or metallothioneins as low molecular mass cysteine-rich proteins, and metallochaperones present within the bacterial cell.
- Various parameters which need to be optimized are pH, temperature, salinity, media composition, biochemical and physiological features or genetic variability of biomass and toxicity of metals towards biosorbents. A variety of microbial strains like *Cyanobacteria*, *Pseudomonads* and M*ycobacteria* have the ability to synthesize metal-binding proteins which can be further used for the removal of zinc, copper, cadmium, mercury and lead (Thi Pham et al. 2022).
- The removal of metal ions can also be carried out by a complex mechanism of releasing EPS like proteins, DNA, RNA and polysaccharides resulting in the slippery layer on the outside of the cell wall. These further retard the penetration of metals within the intracellular environment. *Stenotrophomonas maltophilia*, *Azotobacter chroococcum* and *Bacillus cereus* possess the ability to secrete EPS. Bioremediation efficiency by this mechanism relies on the type and amount of carbon source available and other abiotic stress factors like pH, temperature and the growth phase of each bacterium.
- The functional groups like carboxyl, phosphonate, amine and hydroxyl groups present in the cell walls of bacteria are able to bind heavy metal ions present in the wastewater and their further removal. The efficacy of biosorption depends on the diversity of cell wall structures. Gram-positive bacteria have been shown to contain a high sorption capacity because of their thicker peptidoglycan layer.

Biosorption is commonly used for the removal of lead and chromium from industrial effluent. It involves the use of viable or non-viable microbes for pollutants removal from aqueous solutions and industrial wastewater. Most commonly used biosorbents for the removal of heavy metals from industrial effluent are microbial biomass (Volesky and Holan 1995), and biological wastes like peat and nut shells, coconut shells, rice husk, tea waste, peanut hulls, almond shells, peach stones, citrus peels, (Reddad et al. 2022; Saeed et al. 2005; Khan et al. 2004; Chockalingam and Subramanian, 2013). These biosorbent materials are economical, high sorption efficacy, metal specificity, no sludge generation, regeneration and metal ion recovery (Tunali et al. 2006) and environmentally safer to use (Husoon et al. 2013). The presence of various functional groups like carboxyl, hydroxyl, sulphate, phosphate and amino groups in biological sorbents further assist in binding of metal contaminants from wastewater (Fig. 11.2).

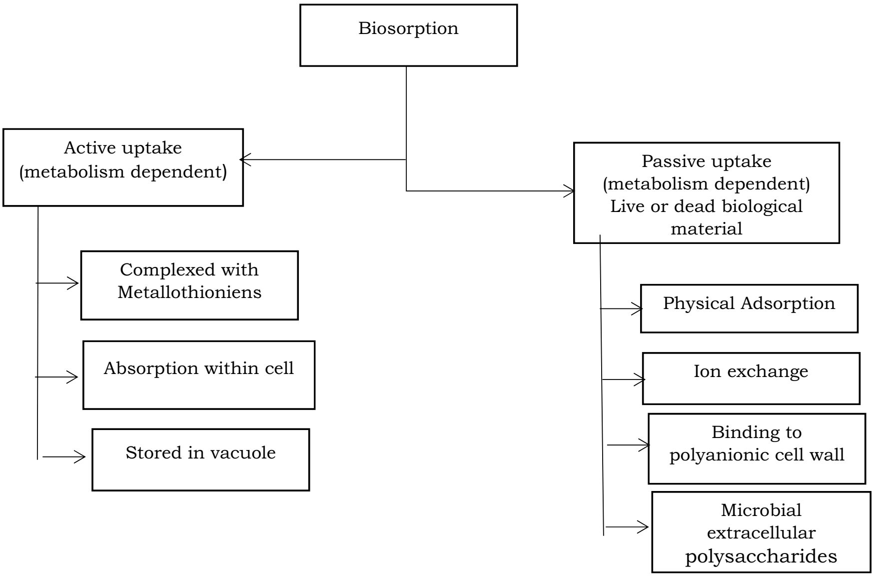

Fig. 11.2 Flowchart showing the mechanism of biosorption by microbial biomass

11.5.2 Factors Affecting the Efficacy of Sorption of Metals Contaminants: (Shartooh et al. 2014; Yarkandi et al. 2014; Dehagni et al. 2023)

- pH, Temperature, moisture,
- shaking speed, incubation time, aeration,
- initial concentration of metal and chemical nature of each contaminant, chemical state of the site or availability and affinity between site and metal or binding strength,
- chemical characteristics of metal like ionic potential, ionic radius, ionic stability limit,
- amount of biosorbent, size of the biomass, number of sites of biosorbent material, the accessibility of sites,
- interaction between different metallic ions and ionic strength,
- toxicity of the pollutants to viable microbial cell (Regine and Volesky, 2000),
- shaking or stationary conditions.

11.5.3 Biological or Agricultural Waste as Biosorbent for the Removal of Lead from Wastewater

Banana peel was successfully used as biosorbent for the lead ions removal from an aqueous solution, and the impact of varying operational conditions in a batch mode was investigated. The maximum lead removal was observed at 98.146% under optimized conditions of lead concentration 100 mg/L, pH 5, amount of sorbent 0.55 g and sorbent size 75 μm (Afolabi et al. 2021).

Certain researchers showed the maximum adsorption efficiency of banana peels for chromium, cadmium and lead and considered it as the inexpensive household waste (Ajmi et al. 2018).

Biochar prepared from agricultural, animal and wood residues proved to be efficient sorbent for lead removal owing to the binding of various functional groups like phenol, carboxyl and hydroxyl to metal ions. While modified clays such as montmorillonite, bentonite, kaolinite, vermiculite, polymeric hydrogels are mostly used for the removal of lead and mercury from wastewater (Aranda and Rivas 2022).

Various agricultural wastes like stems, roots, fruit peels, rinds, saw dust, husks, hulls, dried leaves, fruit shells and seeds have been efficiently used to remove metal contaminants from synthetic solutions (Sun and Shi 1998; Al-Asheh and Duvnjak 1998; Meunier et al. 2003; Sekhar et al. 2003; Wang and Qin 2005).

The peels of grapes were also used to remove lead, copper and zinc from factory wastewater. The fresh fruit peels, dried small pieces and powdered peels were tested for treatment of heavy metal–loaded wastewater by optimization of various parameters like pH, temperature and exposure time, concentration of metal contaminants. The highest removal efficiency was for lead metal as compared to copper and zinc. The Fourier transform infrared spectroscopy analysis (FTIR) studies illustrated that hydroxyl, carboxyl and carbonyl groups were the major binding sites for Pb, Cu and Zn ions removal using grape fruit peels (Shartooh 2012).

Maize cob was used as sorbent for lead ions removal from synthetic solution. Batch mode of sorption studies were performed under well-optimized experimental conditions of 500 ppm concentration, 2.5 g dosage, 400 min exposure time, 400 rpm agitation speed and 5 pH. The efficiency of removal for Pb (II) ions was 95% using maize cob as adsorbent, and studies can be further extended for the treatment of metal-contaminated wastewater (Muthusamy and Murugan 2016).

Activated carbon prepared from leaves of medicinal plant *Militia ferruginea* was utilized efficiently for the removal of Pb (II) ions from wastewater. The maximum adsorption of lead was more than 97% from industrial effluent at 3 h of contact time for 4.0 g of adsorbent and at pH of 4.0. The amount of lead ion adsorbed per gram of the adsorbent increased with decreasing concentration of Pb^{2+} ions. The percentage of adsorption had increased with the increasing temperature (Mengistie et al. 2008).

Undaria pinnatifida was immobilized in sodium alginate beads and further utilized efficiently for the removal of Pb(II) ions from wastewater. To understand the mechanism of sorption, the resulting biosorbent was characterized by Fourier transform infrared spectroscopy (FTIR) and scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM–EDS). The effect of various conditions on Pb (II) ion removal efficiency such as temperature, pH, ionic strength, time and underlying biosorption mechanisms was also observed (Namkoong et al. 2022).

11.5.4 Bacteria as Biosorbent for the Removal of Lead from Wastewater

Positively charged metal ions can be easily removed by Gram-positive bacteria having higher electronegative charge density which might be due to the presence of teichoic and teichuronic acids linked by phosphodiester bonds which are further attached to peptidoglycan layer in the cell wall. The presence of various functional groups having oxygen, nitrogen, sulphur or phosphorus in bacterial cells are responsible for metal ion removal from wastewater (Redha 2020) (Table 11.2).

Bacterial proteins were utilized for the treatment of lead-contaminated wastewater. Lead oxide nanoplates were synthesized by interactions, and the removal of lead ions was confirmed using various advance techniques of inductively coupled plasma analysis, X-ray spectroscopy and X-ray diffraction (Ghosal et al. 2021).

Table 11.2 Examples of microbial biosorbents for lead removal from wastewater

Microbial biosorbents	Examples
Bacteria	*Bacillus* sp., *Pseudomonas* sp., *Arthrobacter* sp., *Alcaligenes sp.*, *Azotobacter* sp., *Rhodococcus sp.*, Acinetobacter *sp.* and methanogens *Pseudomonas putida, Pseudomonas aeruginosa* and *Escherichia coli, Bacillus thuringiensis, Streptomyces sp., Cellulosimicrobium funkei, Lactiplantibacillus plantarum, Cellulosimicrobium sp., Methylobacterium sp., Aerobacillus pallidus, Arthrobacter viscosus, Klebsiella pnuemoniae,, Rhodotorula* sp., *Bacillus megaterium*, *Vibrio parahaemolyticus*, *Klebsiella* sp, *Staphylococcus epidermidis, Oceanbacillus profundus, Micrococcus luteus, Flavobacterium, Enterobacter, Acinetobacter sp., Micrococcus luteus, Bacillus subtilis, Aspergillus niger* and *Penicillium sp*
Fungi	*Aspergillus* sp., *Penicillium* sp., *Rhizopus* sp., *Mucor* sp., *Alternaria* sp., and *Cladosporium* sp, *A. ferrooxidans* and *A. thiooxidans, Desulfovibrio desulfuricans, Coprinopsis atramentaria, A. niger, Rhizopus oryzae, Saccharomyces cerevisiae*, *Penicillium chrysogenum*, *Candida sphaerica*
Yeast	*Hansenula polymorpha, S. cerevisiae, Yarrowia lipolytica, Rhodotorula pilimanae, Pichia guilliermondii*, and *Rhodotorula mucilage*
Algae	*C. vulgaris, Gelidium amansii*, *Phormidium ambiguum*, *Porphyra leucosticte*, *Spirogyra sp.*, *Sargassum muticum*, *Chlorella miniate* and *Spirulina platensis*

Source (Thi Pham et al. 2022; Kumar and Goyal 2009; Kareem and Anwar 2020; Amasha and Aly 2019; Olusola and Aransiola 2015; Rao and Bhargavi 2013; Sheba and Nandini 2016; Villegas et al. 2018; Iram and Abrar 2015; Rastogi et al. 2019; Aracagok 2022)

A continuous column treatment setup was developed in up-flow anaerobic sludge blanket reactor (UASB) loaded with anaerobic sulphate-reducing bacteria and used for the continuous removal of lead and mercury ions from wet flue gas desulfurization (FGD) wastewater. Lead and mercury were removed in the form of sulphides and gets accumulated in sludge. The reactor was operated under various optimized experimental conditions at metal loading rates of 9.2 g/m^3d Pb (II) and 2.6 g/m^3d Hg (II) for retention time of 50 days. The UASB reactor removed $72.5 \pm 7\%$ of sulphite and more than 99.5% of both Hg(II) and Pb(II) and found to be very efficient for the treatment of metal-contaminated wastewater (Zhang et al. 2016). In another similar study, lead was removed from sulphide-rich effluent using sulphate-reducing bacteria in the form of lead sulphide precipitate. The whole treatment was performed in UASB reactor in a continuous mode with initial feeding load of effluent containing 45–50 mg/L concentration of lead ions. The maximum lead removal 85–90% was achieved in UASB reactor (Hoa et al. 2007).

The efficiency of metal tolerance and accumulation of about 164 isolated heterotrophic bacterial strains was studied especially for lead, cadmium and zinc. The metal tolerance studies of all the isolated bacterial isolates showed that about 45% of the total isolates showed very high tolerance of greater than 6000 μg/ml towards lead ions as compared to cadmium and zinc towards which bacterial strains have comparatively low tolerance. Further, one of screened bacterial strain *Bacillus sp.* was found to be more efficient in the bioaccumulation of lead ions (Varghese et al. 2012).

11.5.5 Fungi as Biosorbent for the Removal of Lead from Wastewater

Many metal-tolerant fungal strains were isolated from sewage sludge and industrial wastewater especially tolerant towards lead, cadmium, chromium and nickel. These isolated fungal strains were characterized through various morphological, biochemical and genetic identification tests. The identified and screened fungal strains were *Aspergillus foetidus*, *Phanerochaete chrysosporium*, *Aspegillus awamori*, *Rhizopus sp.*, *Aspergillus flavus*, *Trichoderma viridae* which were further used for the removal of different metals from wastewater. The screened fungal strains were found to tolerate and ability to grow up to 400 ppm concentration of cobalt, lead, cadmium, chromium, copper and nickel metal ions. All the above-mentioned fungal strains have the remarkable efficacy to be used as biosorbent for the removal of cobalt, lead, cadmium, chromium, copper and nickel metal ions from wastewater and industrial effluents (Dwivedi et al. 2012).

The efficacy of non-viable biomass of *Penicilluim sp.* was estimated for the removal of lead ions from synthetic solution. All the treatments were done in the batch mode under optimized conditions of 10 mg/l lead ion concentration, 1 g/l biomass dosage, 2 h of exposure time and found to achieve 78.03% removal of lead ions. The mechanism of sorption found out the involvement of carbonyl, methylene, phosphate, carbonate and phenolic groups in removal of lead ions from industrial effluent (Rastogi et al. 2019).

The efficiency of fungal biomass *Aspergillus neoalliaceus* for sorption of lead ions as a function of pH, biomass dosage, contact time and initial lead concentration was studied. The removal of lead ions with *Aspergillus neoalliaceus* followed Langmuir isotherm and pseudo-second-order kinetic models compared to other used models (Aracagok 2022).

The pre-treated biomass of *Aspergillus niger* was found as an efficient sorbent for the removal of heavy metals especially lead and nickel from wastewater. The various optimized experimental conditions for maximum removal of lead and nickel were pH of 7 and 6 and equilibration time for maximum biosorption at 5 h and 8 h, respectively. In the presence of co-ion lead, the percentage removal of nickel was 92% which was greater than using the single metal system removal (Rao and Bhargavi 2013).

The agricultural waste edible fungi residue was found to adsorb 76.34% of Pb (II) ions from wastewater. All the treatments were performed under optimized experimental conditions of 483.83 mg/L of lead ion concentration, 4.99 g/L of fungi residue at pH of 5.89. The FTIR characterization of fungi residue both before and after treatment confirmed the involvement of various functional groups which controlled the sorption of heavy metals (Jing et al. 2021a, b).

11.5.6 Algae as Biosorbent for the Removal of Lead from Wastewater

The various factors like the presence of functional groups, high surface area and high binding capacity in algae make it an efficient sorbent for the removal of heavy metal ions especially lead ions from wastewater. This might be due to the presence of chitin, polysaccharides, proteins and lipids in cell wall of algae resulting in higher biosorption ability (Davis et al. 2003). In the first rapid extracellular passive sorption, heavy metals are adsorbed over the cell surface by not involving cellular metabolism. The various factors like bioavailability of metals, availability of metal-binding groups on the algal cell surface, metal uptake and storage efficiency of algal cells determine the efficacy of sorption. Biosorption can be carried out by both viable and non-viable biomass. Algae can either exchange metal ions with calcium, magnesium, sodium or potassium ions or form complex with the functional groups on the surface of algal cell. Contaminants can easily bind to the surface of algae due to the presence of polysaccharides, lipids and proteins. The presence of sulphate, carboxyl, amino and hydroxyl groups in the cell wall of microalgae makes it suitable as the binding site for the pollutants. Heavy metals can also be transported across the cell membrane within the cytoplasm or organelles through an active uptake and can be carried out by viable biomass only and also dependent on cellular metabolism. This process is also known as slow intracellular active accumulation and requires energy for the accumulation of heavy metals inside the microalgal cells.

Various self-defence mechanisms of gene regulation, complexation, ion exchange, chelation, produce reducing agents or anti-oxidants and cause heavy metal immobilization enhances the efficiency of algae to fight against the toxicity of heavy metal ions (Chugh et al. 2022).

The algae *Chlorella vulgaris* has the ability to remove various heavy metals, especially lead and cadmium in one metal solution system (Moustafa and Idris 2003). The mechanism of sorption revealed that the removal of lead occurs in two consecutive steps, the first is the adsorption on its surface followed by fixation. The algae was able to remove 60% lead and 65% cadmium efficiently from synthetic solution (Dhokpande and Kaware 2013; Sonali et al. 2013).

Sludge-based adsorbent was prepared by ferric activation through pyrolysis and further used for the sorption of lead ions from aqueous solution. The ferric-activated sludge-based adsorbent showed a favourable porous structure development and lead ions removal with the maximum sorption capacity of 42.96 mg/g (Yang et al. 2019).

11.6 Conclusions

This review article summarizes the various sources of heavy metal contamination along with the hazards of especially lead-contaminated wastewater, their current physiochemical treatments and their limitations. This review also highlighted the biosorption technology used for the treatment of lead-contaminated wastewater along with the in-depth knowledge of major mechanisms involved through which biosorbents remove metals from wastewater. Furthermore, a brief discussion on the effect of lead contamination on various components of ecosystem and remediation of heavy metals using an elaborated list of biosorbents has been reviewed. To make this bioremediation technique more efficient and successful, recent advancements, challenges and strategies to carry out in the future have been explored. The need of biosorption, factors affecting sorption, utilization of biological waste as biosorbents has been detailed. It has been concluded from detailed literature survey that the use of biosorbents seems to be a more promising alternative for the removal of lead ions from wastewater as compared to the other conventional methods of treatment. These biosorbents can be either plant- or animal-originated or microbial biomass. Microbial sorbents can be used in form of live or dead biomass, more economical, pollution free, easily availability and regeneration ability, effectively utilized for continuous treatment in columns for industrial waste treatment.

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