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Bioremediation of Heavy Metals: A Substantive Potential for Clean Earth

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Abstract: Modern industrial and agriculture developments, anthropogenic activities effected terrestrial and aquatic pollution of heavy metals posing serious threats to biotic (human/animal/plant) and environmental health, as well as, welfare of any nation. Phytoremediation of metal polluted sites has attracted worldwide significance due to its being less expensive and environment-friendly properties. Robust information is available on heavy metal remediation, phytoremediation and several plants are recorded worldwide which hyper accrue wide category of heavy metals. This communication emphasizes various remediation methods, especially phytoremediation for heavy metals along with its advantage compared to other techniques. Phytoremediation technique is specifically applicable for reclamation of sites with low to moderate pollution level due to its being energy efficient and aesthetically pleasant, also it can be co-practised with various conventional remedial processes as an ultimate procedure for remediation process.

Keywords: Biosorption, phytobioremediation, phytostabilization, rhizofiltration, phytolatilization

1. Introduction

Pollution due to heavy metals is an alarming global threat for their toxicity even at low concentrations. Higher heavy metal concentration produces free radicals effecting oxidative stress, as well as, substitute essential metals. Soil and environmental characters modulate accretion, mobility and hazardous conversion of heavy metals. Some metals are naturally present in lower concentration in soil which exert no toxic effect are known as the essential elements, or trace elements or micro nutrients. Contrastingly, some non-essential metals which put forth deleterious consequences are known as toxic elements. Widely promoted anthropogenic or human caused activities lead to metal pollution and possess serious hazards as toxic metals are not included under nutritional requirements of plants too but would act as contamination sink. Aerosols, power plants based on coal, smelting or metal extraction factories, chemicides, fertilizers used, sewage removed openly, sludge and waste products of mines are foremost factors of pollution due to heavy metal. Among them, industrial biproducts and agricultural activities are primarily accountable for soil pollution, and enhanced industrialization and modern farming systems during last few decades have worsened the situation. Central Statistical Organization recorded increased fertilizer and pesticide use in agriculture by 80 % (7.7-13.9 million tonnes) and 240 % (24305-85030), respectively, during 1984-1996 (Kapahi *et al.*, 2019).

1.1 Remediation Technique

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Remediation contaminated soil is globally practised for reclamation. For remediation of metal-contaminated sites, the wide category of methods those have been developed are grouped broadly into 3 types. These are: physical, chemical and biological methods. These methods used either singly or in various combinations or sequentially one after another are highly efficient for partial to complete metals removal from soil or even for reduction of their bioavailability and diminishing toxicity. Identification and implementation of remediation methods are determined from nature and extent of metal pollution, character and type of contaminated site, operational cost, availability of facilities and regulation obligations (Malik *et al.*, 2012).

1.2 Physical Remediation

Physical remediation is the oldest practice of soil reclamation. For initiating physical remediation, prior knowledge about the physical characteristic of the site to be remediated and also the category and extent of pollution must be acquired. The characterization of contaminants to determine the type, category, concentration, reactivity and spreads of heavy metal is must to choose the type of remediation. Also, the total metal concentration and the leachable metal assessment can determine the risk of physical remediation. Physical remediation follows capping, mixing, washing, excavation, solidification of soil for rapid cleaned up but higher cost and possibility of contaminant shifting undermine the method of removal of heavy metals from contaminated site. Physical remediation of heavy metals varies depending on the physicochemical properties of the metal. Thus, it may include adsorption, solidification, electric field application, membrane filtration, granular activated carbon, photocatalytic reactors (Akhtar *et al.*, 2020), However, their limitations include high cost, inefficient for low range of contaminants and irreversible changes in the soil leading to deterioration of ecosystem and increase of secondary pollutants.

1.3 Chemical Remediation/*In Situ* Fixation

Chemical remediation includes techniques such as chemical reduction, floatation, ion exchange, coagulation, flocculation. Chemical remediation advocates transformation of heavy metals in polluted soil by chemical application to lesser toxic form but plants cannot easily absorb them. So, during stabilization, soil retains the heavy metals but reduced harmful state and higher success rate of the technique made it popular procedure. The process requires periodic treatment and designate equipment and specialized operators. The method effect’s physical structure and reduces biological activity in the treated soil which makes it inapplicable in large scale heavy metal reclamation (Malik *et al.*, 2012). Chemical remediation is very efficient but not preferred due to extensive practice of chemicals, shortcomings in disposal of sludge and high chances of pollutions due to secondary products. Nano-remediation is an emerging method and branch of chemical remediation in which environmental heavy metals are eliminated using nanoparticles. Removal of Cr and Zn has been shown to be efficiently done using a combination of biological and chemical method. This method demonstrates use of green-synthesized copper iodide nanoparticles and iron oxide nanoparticles (Akhtar *et al.*, 2020).

2. Management of Heavy Metal Contaminated Soil and Their Strategies

Manufacture of various industrial products release various heavy metals inadvertently. Problems arising due to toxicity, bioaccumulation and metal persistence they act as serious pollutants to environment. Microorganisms can be used as treatment for metal contaminated soils due to their ability to bioremediate by altering the reactivity and mobility of the metal contaminants. Using microbes for bioremediation has various preferences due to their wide natural availability, cost-effective production and highly selective mode of removal and recovery of specific metals. The following points explain the general processes of bioremediation of metal contaminated soil environment. The numerous environmental components that influence the rate of biodegradation are discussed along with the advantages and limitations of *ex situ* and *in situ* bioremediation (Dhankhar *et al.*, 2011).

2.1 Basic Concepts

Bioremediation is a quickly expanding and updating area of research and application. It is highly preferred to the conventional physico-chemical methods, as it offers more efficient and cost-effective methods of remedial techniques. It primarily promotes the use of microbes to remediate contaminated soils, aquifers, sludges, residues and air. A successful bioremediation program demands proper design and implementation backed up with technically complex, comprehensive experience and expertise. As a successful bioremediation has to encounter multiphasic, heterogenous environments including soil, its success in terms of effectiveness is dependent on a multidisciplinary approach including streams of chemistry, engineering, geology, microbiology and ecology. The promising results of initial researches created a bio-enthusiasm in the early years and inspired for setup of many remediation companies. It resulted a more realistic view, but sometimes slight sceptical concept of bioremediation. As the results obtained in the laboratory experiments did not always reproduce actually in contaminated site, since it was not possible to imitate all the changing environment of a realistic situation. Most of traditional remedial measures do not offer acceptable outputs keeping in concern the heavy metals’ remediation from contaminated soils. On the other hand, microorganisms use metals' ionized state for terminal electron accept. Otherwise, they reduce the metals during the detoxification mechanism. Hence, they could be used for heavy metal remediation from contaminated area. Phytoextraction of metals is another lucrative technique that incorporates the use of metal-accumulator plants to remediate the metal contaminated soils (Garbisu *et al.*, 2003; Igiri *et al.*, 2018; Ojuederie *et al.*, 2017).

2.2 Use of Chelating Agents

Biodegradable as well as chelating agents such as chitosan and ethylenediamine tetra-acetic acid (EDTA) were used in comparison with the reaction of a reference compound such as sodium citrate for clean-up oof of copper and nickel from samples of artificial-contaminated soils. The results of the study demonstrated that the removal capacity for copper and nickel decreased from the polluted area in the decreasing order of chitosan > EDTA > sodium citrate. The major factor that controlled the extraction was the pH of the eluents, especially the chitosan solution. The most efficient pH range of the Chitosan solution was 3.3 to 5.0. The copper and nickel extraction rate being were 43.36 %, and 37.07 % respectively with the concentration of contaminants were 0.3 g/L and 10 mL/g respectively (Jiang *et al.*, 2011).

2.3 Bioremediation of Contaminated Water Containing Heavy Metals

Bioremediation is listed among the preferred technologies for decontamination of sites contaminated containing broad range of pollutants, as it is cleaner, cheaper and safer to the environment. Bioremediation is the process of removal of toxic waste from environment by using different type of biological agents. Bioremediation has been proved as the most effective tool for management and recovery of heavy metal contaminated soil. Bioremediation process involves use of various biological agents including bacteria, and lower plants like fungi, algae or higher plants which serve as the major tools in treatment of heavy metals contaminated areas. Both *in situ* and *ex situ* bioremediation have been supported due to relevant scientific evidences, partially also because of augmented use and natural attenuation, as most of the natural attenuation occurred due to biodegradation. Bioremediation along with natural attentiveness are thus observed as the solutions for emerging contamination issues. Hence, microbes are the major tools to remediate the heavy metal contaminated areas (Kulshreshtha *et al.*, 2014).

3. Biological Remediation

Biological remediation is broadly grouped into two categories: (a) Bioremediation (executed by use of microorganism), and (b) Phytoremediation (executed by use of higher plants). Pollution due to heavy metal contamination has now become the most alarming requiring serious concern. Anthropogenic or excavation activities including metalliferous mining, smelting, disposal of industrial and agricultural waste containing of varieties of metals such as lead (Pb), silver (Ag), mercury (Hg), arsenic (As), nickel (Ni), gold (Au), copper (Cu), cadmium (Cd), chromium (Cr), cobalt (Co), platinum (Pt), palladium (Pd), tin (Sn), rhodium (Rd), zinc (Zn), thorium (Th), and uranium (U). These can exert harmful consequences on health and growth of living beings when consumed in higher amounts without being further processed to harmless by-products by the organisms. Both physical and chemical methods were suggested for the removal of these heavy metal pollutants. Conventional methods of heavy metals remediation include processes such as excavation, solidification or stabilization. These technologies are appropriate to temporarily reduce the contamination level but cannot be used for continuous removal of heavy metals for prolonged period of time. Moreover, they have listed disadvantages too. The disadvantages of physical and chemical method of remediation are cost-ineffectiveness, generation of hazardous by-products and not highly inefficient. On the contrary, biological remediation methods have overcome these limitations due to their easy operation process and no secondary pollution of by-products. Heavy metals tend to be toxic at low concentrations too due to their high density. Basically, the microorganisms and plants are used under biological remediation methods for removal of the heavy metals from the contaminated sies. The processes involving of microorganisms for decreasing the pollutant's concentration are known as bioremediation, and these are mostly natural processes. Thus, their importance of biodiversity and abundance above or below the earth level is increasingly important for remediation of metal decontamination and clean-up of polluted environment.

3.1 Textile Industry Dye Effluents' Bioremediation Using Bacterial Strains

In present day issues, water pollution is the major global threat. Industrial effluents discharged in an untreated state into the water bodies pose serious concern for the aquatic organisms and living beings in the same ecosystem. The textile industries have driven major attention among the industries causing pollution by environmentalists. They incur consumption of large volume of water and utilization of dyes as well as chemicals for manufacturing of textiles and various related processes. Textile effluents are also found to contain toxic wastes of organic and inorganic compounds, carcinogenic dyes and aromatic amines. Most of the conventional methods including physico-chemical methods are not highly effective for the removal of the metals from effluents discharged from textile industry. On the other hand, microbial bioremediation is a highly effective approach which offers total and efficient removal of heavy metals such as Pb, Zc and Cd from the dye effluents of textile industries. For the bioremediation of textile dye effluents enriched with heavy metals, four bacterial strains were found to be heavy metal resistant in recent studies. These are *Salmonella typhi, Escherichia coli, Pseudomonas fluorescence* and *Bacillus licheniformis*. The studies demonstrated high efficiency of these bacterial strains for removal of heavy metals from the dye effluents of textile industries (Ayangbenro *et al.*, 2017; Chibuike *et al.*, 2014).

3.2 *Pseudomonas Putida* Mediated Biosorption of Cadmium

Industrial waste and sewage are posing serious threat and is enormously growing in most of the developing countries. Some of the heavy metals damage the organ system of human and other living beings to extreme extent. Their efficient detoxification demands good potential for constant application of toxic heavy metals in bioremediation. Cadmium is the highly influenced heavy metal that has shown to efficiently remediated from contaminated soil by the use of microbes. Microorganisms have enormous ability of absorption of Cd from a medium. The removal of cadmium ions was executed recently using biosorption method in aqueous solutions by use of bacterial culture. Results of this study showed that growth of *Pseudomonas putida* culture biomass was associated with the decrease in Cd concentration in the growth medium. Thus, only ~20 % of the *P.putida* bacteria could grow in a medium containing up to 40 mg Cd/L. The results of the study indicated that the living biomass of the bacterial cultures of *P.putida* was more efficient in absorbing Cd contamination. However, it was late revealed that a medium containing formulation of yeast and peptone, fortified with cultures and ingredients promoted best growth yields and had the most increased absorption of Cd. However, absorption of Cd by *P.putida* was significantly influenced by various factors including pH of the medium of absorption, contact duration, amount of biomass and Cd concentration. Thus, from a medium with initial concentration containing 10 mg Cd with culture of *P.putida*, 93 % of Cd was absorbed (Nanganuru *et al.*, 2012; Chellaiah *et al.*, 2018).

3.3 Bioremediation by the Microbial Consortia from Spent Oil Contaminated Site and Poultry Litter

Structure of heavy metals are metallic chemicals with high-density. Thus, they can be high toxic even at sub-detectable concentrations and pose threat to health and growth of all living being in an environment. Microorganisms in animal wastes ascertained the efficiency of bioremediate the heavy metals found in contaminated soil containing spent engine oil. In Ugbowo, Edo State, Nigeria, contaminated soil containing spent engine oil was extracted in a mechanical workshop and carried to laboratory. Spent engine oil containing soil samples were air dried followed by homogenization. These were used as cells to be tested and further thoroughly mixed with different proportions of poultry litter-based manure. The study was carried out for ten weeks and observations of soil pH, microbial counts and heavy metals' concentration were recorded periodically on a weekly basis. Results of this study indicate that pH of the control soil was 6.9 in initially while it ranged from 8.1 to 8.4 for the proportionally different categories containing different amounts of poultry manure. Soil moisture content at the start of experiment was 2% which was improved to 17.8 % - 18.4 % after watering. While the moisture content in the reference sample was 18.9%. Thus, the moisture content was increased equivalent to the reference after bioremediation. Microorganisms recovered from the poultry litter and spent engine oil contaminated soil samples were identified and included several bacterial species including *Corynebacterium*, *Pseudomonas*, mould, *Penicillum*, *Enterococcus*, *Acinetobacter*, *Micrococcus*, *Bacillus*, *Arthobacter*, *Sachoromyces*, *Klebsiella*, and *Trichoderma*. Analysis of the heavy metals indicated reduction of arsenic (mg/kg) by 2.73 %, barium by 6.28 % reduction, cadmium by 25 %, respectively, in the control sample. Removal of cadmium in the treated categories were insignificantly varying and more or less similar with the control. While Cr reduction in the control sample was 20 %, its reduction in the PL 20 % + SEOCS sample (Poultry Litter + Spent Engine Oil Contaminated Soil), PL 30 % + SEOCS sample and PL 40 % + SEOCS sample were 26 %, 58.06 % and 46.57 %, respectively. In the untreated sample, cobalt was reduced by 5.86 %, lead (mg/kg) was reduced by 2.70 % and lead ($P<0.05$) reduction was significant over control. These research findings suggested that removal of heavy metals in soil can be done by addition microorganisms or present inherently in the contaminated soil and animal wastes using the above-mentioned bioremediation procedures (Adams *et al.*, 2014; Leal *et al.*, 2017; Kapahi *et al.*, 2019; Endeshaw *et al.*, 2017).

3.4 Fungi Mediated Biosorption of Heavy Metal Polluted Soil

Microorganisms are the major players in biosorption of heavy metals which help in heavy metal contaminated soil and water. The environmental contamination due to heavy metals is continuously increasing due to the massive industrialization. To control metal pollution, various biotechnological methods are applied, of which biosorption is the major one. Biosorption efficacy of *Aspergillus fumigatus* against several metals including Zn, Cd, Cr, Pb, Ni, and Cu at pH 5 and 30 ºC temperature with 200, 400, 600 and 800 ppm metal concentrations were investigated. The highest biosorption by *A. fumigatus* isolate K3 was exhibited for Pb (76.07 ppm) decreased through Cu (69.6 ppm) and finally by Cr (40.0 ppm) at 800 ppm metal concentration. After this results several workers accessed the management of natural biosorbent (*A. fumigatus*) for treatment of industrial effluents with toxic metallic ions in a more economical method (Shazia *et al.*, 2013). Fungi of *Aspergillus species* were isolated from the waste water treated soil samples of Hudiara drain, Lahore. They were found to be heavy metal resistant when tested for their effectiveness for heavy metal removal by testing for the factors of such as optimum pH, temperature, initial metal concentration and contact time in these isolates. Biosorption efficiency of two Aspergillus species namely *A. flavus* and *A. niger* was determined by testing for heavy metals like for Cu (II) and Pb (II), respectively. While the optimal pH of bioremediation was determined to be 8-9 and 4-5.4, the optimal temperature for bioremediation was fixed in the range between 26 °C and 37 °C for *A. flavus* and *A. niger* respectively. Further, with starting concentration of 200-1400 ppm the biosorption efficiency of *A. flavus* was 20.75-93.65 mg/g against Cu (II). On the other hand, with the same starting metal concentration biosorption efficiency of *A. niger* against Pb (II) ranged between 3.25-172.25 mg/g. It was also observed after maximum adsorption, an equilibrium was maintained. The adsorption data fitted to Langmuir model showed that the coefficient of determination was < 0.90. The results of this study served as a base for further research on bioremediation of polluted soils (Iram *et al.*, 2015; Manguilimotan *et al.*, 2018; Acosta-Rodríguez *et al.*, 2019). Due to rapid industrialization and urbanization heavy metals' concentration from contaminated soil is increasing rapidly, however fungi can serve significant contribution for their biosorption. Hence, the development of new bioremediation programs for heavy metal contaminated soils is the need of the present scenario. A study was conducted to screen fungal resistance against heavy metals such as Pb, Ni, Co, Cr, Cu, Mn and Zn revealed that the threshold of tolerance for a *Neurospora* sp. for Mn (60 mg/ml), Cu (5 mg/ml), Co (5 mg/ml), Pb (4.5 mg/ml), Ni (6 mg/ml) and Cr (3.9 mg/ml), and for *Penicillium* sp. for Zn was 80 mg/ml respectively. Maximum growth of the *Neurospora* sp. at the threshold concentrations of metals was observed at pH 5 and along with 30 °C in presence of Mn, pH 5 at 32 °C with Cu, pH 5 at 30 °C for Co, pH 5 at 31 °C for Pb, pH 5 at 30 °C for Ni, pH 5 at 29 °C for Cr and at pH 4 at 30 °C for zinc respectively. The results also revealed that antibiotic resistance and metal resistance were highly coordinated in terms of removal. *Neurospora* sp. was observed to have multiple antibiotic resistance with improved UV mutagenesis and resistance against Zn up to 82 mg/ml (Joshi *et al.*, 2014; Wang *et al.*, 2017; Yada *et al.*, 2019; Hoque *et al.*, 2019).

Table 1 - List of fungal species efficient for bioremediation of heavy metals

Name of the Organism	Temperature (°C)	pH	Heavy metal remediated	Range of remediation
Aspergillus fumigatus	30	5.0	Lead (Pb)	76.07 ppm
			Copper (Cu)	69.6 ppm
			Chromium (Cr)	40.0 ppm
Aspergillus flavus	26	8.0 – 9.0	Cu (II)	20.75-93.65 mg/g
Aspergillus niger	37	4.0 - 5.4	Pb (II)	3.25-172.25 mg/g
Neurospora sp.	30		Manganese (Mn)	60 mg/ml
	32		Copper (Cu)	5 mg/ml
	30		Cobalt (Co)	5 mg/ml
	31		Lead (Pb)	4.5 mg/ml
	30		Nickel (Ni)	6 mg/ml
	29		Chromium (Cr)	3.9 mg/ml
Penicillium sp.			Zinc (Zn)	82 mg/ml

3.5 Bioremediation of Pulp and Paper Mill Effluent by Indigenous Microbes

Indiscriminate and uncontrolled release of industry effluents with metal contamination into the nearby ecosystem is a serious issue and drags major concern. Discharge of heavy metals without adequate treatment creates significant threat to public health due to its persistence, accumulation and even bio-magnifications in food chain. To reduce the problems associated with metal pollution many methods have been developed including steps for treatment and disposal of metal containing wastes and effluents. The major drawbacks of conventional treatments are less efficient at lower concentration of heavy metals, cost-effective handling and absence of safe disposal methods of toxic sludge. Microbial bioremediation of metal is an effective strategy due to its being cheap, highly efficient and environment-friendly in nature. Moreover, it can lead to partial or complete biotransformation of wastes including microbial biomass and stable end products. heavy metal remediation from pulp and paper mill effluents and other associated criteria's such as turbidity, biological oxygen demand (BOD), total suspended solids, chemical oxygen demand (COD) were studied in the medium containing indigenous *Pseudomonas*, *Staphylococcus* and *Streptococcus* spp. Results suggested that *Pseudomonas* sp. could be an efficient microbial tool for heavy metal bioremediation of than their counterparts. These results open new possibilities to remove heavy metal at low concentrations from the waste water of pulp effluents of paper mill using indigenous microorganisms (Hakeem *et al.*, 2010).

3.6 Bioremediation Due to *Serratia Marcescens* in Heavy Metal Contaminated Soil and Water

The antibiotic and metal tolerance patterns of *Serratia marcescens* strains were assessed in isolated samples from soil and water around the Sangam region of Allahabad. The Kirby-Bauer disc-diffusion method using the standard minimum inhibitory concentration (MIC) for each antibiotic was used to obtain antibiotic resistance patterns of the *Serratia* strains. The MIC of the metals - Cr, Cd, Co, Cu, Pb and Ni were studied. To ascertain the transfer of resistance genes which could be plasmid-borne, plasmid curing properties were investigated for specific antibiotic and metal resistances abilities. Results of this study suggested that multi-drug resistance (MDR) *Serratia marcescens* were resistant to certain metals such as Cr, Cd, Co, Cu, Pb and Ni as well as specific for metal-antibiotic resistant gene patterns (Nageswaran *et al.*, 2012).

4. Interactions of Heavy Metals with Microbes and Plants Mediates Bioremediation of Contaminated Soil

For decontaminant or detoxification, the native or introduced microorganisms, biological material such as compost or manures of animal origin are employed. The process is eco-friendly requiring no chemical amendments but requires microbial cultures and bio wastes. Phytoremediation is a plant-assisted bioremediation technique, which has proved highly promising for remediation of contaminated soils *in-situ*. Improvement in the method of phytoremediation needs a thorough and overview knowledge of the complex interactions that occur in the rhizosphere. The effect on remediation of heavy metal due to fungal inoculation was experimented in contaminated soil continuously treated with effluent of sewage for nearly 50 years (long time) under controlled conditions. In this experiment, canola crop was used as the accumulator plants. This result of this study demonstrated significantly higher dry matter yield in the soil that was irrigated with sewage and effluent when compared to the soil that was irrigated with sewage effluent for 20 years. Inoculation with *A. parasiticus* and *F. oxysporum* enhanced the metal uptake and accumulation in different parts (shoot and root) of the plant (Natsheh *et al.*, 2013). Heavy metal polluted soil is a global phenomenon resulted from increased geological or human activities. Contaminated soil seriously hampers growth, performance and yield of plants. Bioremediation by *in situ* treatment of heavy metal polluted samples is very effective and practicable to establish/re-establish crops after treatment of polluted soils. Microbes and plants use differential bioremediation methods of contaminated soils. Exploitation of plants for bioremediation of heavy metal contaminated soils is commonly practised. Approach of combined use of microbes with plants for bioremediation ensures efficient reclamation of heavy metal contaminated soils. However, species combination of remediating organisms is success determinant of the process (Iram *et al.*, 2013). Phytoremediation can be taken as a remediation strategy meant for external sites, as it employs the involvement of plants for removal of the non-volatile and immiscible soil content. Hence, phytoremediation has established itself as the alternative to the traditional remediation methods for treatment of contaminated land which is also sustainable, viable and inexpensive. To further enhance the viability and robustness of the phytoremediation, plants with faster growth higher metal uptake and rapidly growing biomass are gaining are in demand. The role of phytochelators has gained particular attention in the study area of phytoaccumulation that have been carried out in Europe and the USA. Use of phytochelators is specific process in making the heavy metals bio-available to the plant, While, their symbionts have demonstrated enhanced uptake of heavy metals along with increased bio-availability (Khan *et al.*, 2000).

5. Naturally Occurring Heavy Metals in Soil and Their Bioavailability

Presently, main concern of industrialized nations is environmental co-contamination by organo-chlorines with heavy metal contaminants as later one interacts with biodegradation or other metabolic enzymes and inhibits organo-chlorine detoxification. Recent developments for co-contaminated environments bioremediation have emphasized exploitation of metal tolerant bacteria, improved treatment, clay minerals and chelating mediators for reduction of concentration of heavy metal that is bioavailable. Furthermore, phytoremediation is a preferred alternative as the remedial technology of co-contaminated environments. However, investigation (although limited) revealed that metal contamination impedes organic component biodegradation (Olaniran *et al.*, 2013). The deleterious effects of heavy metal pollution and their worldwide awareness of has resulted in elaborate researches to understand metal interactions in soil followed by their effective methods of removal. The study and applications of technologies for degraded soils through the conventional physiochemical remedial methods have existed since ages. However, they are not wide spread and accepted in present day scenario due to their harmful effect on the ecosystem. Contrastingly, phytoremediation has grabbed more attention for treating the polluted lands in a biological and natural way. Additionally, augmented concentration of essential rhizobacteria can also reduce phytotoxicity and increase the remediation of soils polluted due to heavy metal, and this approach has also gained much interest (Nanda *et al.*, 2013). Investigations for isolation of microbes from metal polluted soil, mud and water has recently received priority for heavy metal remediation and screening of such isolates identified 72 acidothermophilic autotrophic bacteria for tolerance of heavy metal with biosorption potential. Besides, tolerance for multiple metals in bacteria could be was induced exposing to increasing concentration gradient of Pb, Ag, Zn, Li, Cu, As, Bi, Cd, Cr, Co, Hg, Mo, Sn and which biosolubilized copper sulfide ores. Such bacteria could mineralize copper by 85.82 % from chalcopyrite and 97.5 % from covellite after 5 days at 55 °C and pH 2.5 with 10 to 3 M of multiple heavy metals analyzed through inductively coupled plasma spectroscopy (ICP). A most potent isolate (ATh-14) demonstrated maximum adsorption for 73 % Ag, followed by 35 % Pb, 34 % Zn, 19 % As, 15 % Ni and 9 % Cr from chalcopyrite (Khanna *et al.*, 2019; Umrania *et al.*, 2006).

5.1 Reduction of Heavy Metals During Composting

Composting has become a more accepted method for treatment of municipal solid waste, sewage sludge, poultry manure, pig manure and tannery waste, etc due to its being more economical. The compost formed from waste material and land can be used as fertilizer or conditioner of soil due to the enrichment of various elements such as N, P, K including several other macro and micro nutrients. Worth noting is higher concentration of heavy metals in the compost limits it from being used as a soil conditioner. Heavy metals are initially taken up from soil by the plants and successively get accumulated in human cells and tissues and further through biomagnifications they establish in the food chain, which causes serious concern to human and environmental wellbeing. Heavy metals concentration can be reduced in the compost samples by adding of several chemicals and biological agents during composting process. The chemicals used in this process include sodium sulphide, natural zeolite, bamboo charcoal red mud, bamboo vinegar, and lime etc. Fungal species such as the *Phanerochaete chrysosporium* are shown to be used for effective removal of lead (Pb) from the compost. Earthworms are also shown to have ability of accumulating higher concentration of heavy metals in their non-toxic form. Further they are capable of reducing the effects due to toxicity by the presence of nonessential heavy metals and utilize them in the metabolic pathways of their own body. The major advantage of the biological over the chemicals process during composting was the investment and running cost. Hence, the present topic provides and overview of the techniques of reduction of various heavy metal during composting of various wastes materials coming out during different operational modes (Singh *et al.*, 2012). Pollution deteriorates soil, water and atmospheric quality and in last two decades immense strategies have been advocated to minimize pollution sources and reclamation of contaminated terrestrial and aquatic ecologies. Higher cost-effectiveness with lesser cons of phytoremediation compared to physical or chemical methods made it most preferred proposition of bioremediation for academics and practicality. More than 400 potent phytoremediating plant species are known to date, out of which *Sedum alfredii*, *Thlaspi*, *Brassica* and *Arabidopsis* species have been well investigated. Modern biotechnological advancements would be helpful to develop potent pollutant hyper-accumulators through hyper-accumulation of metal and gene transfer from low biomass wild species to high biomass cultivars. Present state of art of phytoremediation research and its practical applications in polluted soil and aquatic ecologies (Lone *et al.,* 2008) has been discussed in the review.

6. Phytoremediation

Employment of plants for heavy metal remediation was initiated in 1983 which was designated as phytoremediation. It is derived from Greek word with the prefix ‘phyto’ meaning to ‘plant’ and Latin word ‘remedium’ meaning ‘to remove an evil.’ The process is economical, environment safe and widely accepted technology to for clean-up of heavy metals from the contaminated site or soil. It incurs low-cost compared to the excavation and *in situ* fixation. Heavy metal pollution of soil is universal accompanied with increased geologic and anthropogenic activities In China, soil, water and food were recorded to be heavily contaminated with heavy metals. The use of plants to remediate heavy metal polluted site is an effective technique and also adds to check pollution level (Wu *et al.,* 2021). In order to successfully implement phytoremediation, it is importance to understand the processes of heavy metal accumulation in plants, the removal of pollutants along with role of plants in this process.

Phytoremediation employs use of plants for the extraction procedure from soil as well as water, transfer and stabilization of heavy metals (Cheng *et al.*, 2003). To provide a general outlook of phytoremediation, thorough work has been done in China to explain heavy metals accumulation in plants, their purification and phytoremediation techniques. The results obtained from their studies have been compiled from many Chinese publications mostly in the last decade. It explained the results of study on heavy metals accumulation in plants and the potentiality in controlling heavy metal pollution (Cheng *et al.*, 2003). Plants can do selective uptake of heavy metals through different plant parts including roots, or even stems and leaves, which then accumulate in the respective organs. Accumulation and distribution of heavy metals in the plant organs is influenced by various factors such as plant and element species, chemical form, bioavailability, redox, pH, cation exchange capacity, dissolved oxygen concentration, internal temperature and secretion in the roots (Cheng *et al.*, 2003). Plants are also employed for decontamination of polluted water containing heavy metals. This technique has proved highly performance in treating the industrial effluents and mineral tailing water. Extent of purification of the heavy metals by plants varies according to variation in several factors, including the heavy metals’ concentration, element and type of plant species, interval of exposure, internal temperature and pH (Cheng *et al.,* 2003). Thus, phytoremediation, is a green, environment friendly tool for remediation of polluted soil and water. It involves use of vegetation to eliminate, detoxify or convert the persistent pollutants in to non-toxic form.

The advantages like higher productive biomass and easy disposal methods by the use of plants have become most useful to remediate heavy metals on site (Cheng *et al.*, 2003). Bioremediation of heavy metals contaminated water with *Moringa oleifera* seeds in which it is used as biosorbent has been demonstrated. Phytostabilization involves transcription and immobilization of contaminated metals in roots, reduction of leaching and erosion, development of aerobic environment in rhizosphere and organic matter amendment to immobilize/stabilize the metals (Chatterjee *et al.*, 2013). In the rhizofiltration process the plants that adsorb / absorb metals are uprooted to remove contaminants. It is independent of tolerance or translocation of metals to areal plant parts but should be able to tolerate heavy metals for remediation in higher contaminated soil to enable more accumulation of contaminants. Repeated cropping is essential to reduce the metals concentration to an acceptable limit through phytoextraction which, however, is a lengthy proposition. Although in organically polluted soils phytoremediation is an inherent process but for inorganic contaminant reclamation it is still poorly developed but it is known to reclaim mercury, selenium and boron etc. from soil. Plants adopt three fundamental mechanisms for growth in polluted soil viz. metal excluders where plants retain more heavy metals in roots and restrict movement to aerial part; metal indicators where above-ground plant parts collect metals which would reflects metal concentration in soil and metal accumulator plants (hyperaccumulators) which are capable to concentrate metals aerial parts exceeding the soil concentration level (Huang *et al.*, 2020). Plants accumulating more than 0.1% Ni, Co, Cu, Cr or Pb and 1% Zn in terms of dry weight of leaves are hyperaccumulators irrespective of metal concentration in soil which counts to be 400 species to date. Considering heavy metal accretion in plants crop species and food/fodder pasture herbs for fewer heavy metals accumulation and hyperaccumulator plants to extract contaminated heavy metals from soil and water can be selected. China is researching on mechanisms and application strategies to formulate hyperaccumulation of metals through phytoremediation (Wu *et al.*, 2021; Cheng *et al.*, 2003).

7. Natural Remediation

Unenhanced i.e., non-invasive, otherwise, natural process of remediation strategy is known as natural remediation which is a well-established strategy for remediation of organic pollutants such as BTEX (benzene, toluene ethylene, xylene). However, the natural processes cannot obliterate metal contaminants but sometimes it can immobilize contaminants but it can manage both organic and inorganic pollutants (Malik *et al.*, 2012). Natural remediation means use of cos-effective and non-invasive amendments such as apatite rocks, lime and organic residues, which are added to soil to enhance the natural solubility or mobility of the heavy metals or for bioaccumulation (Adriano *et al.*, 2004). For elimination of volatile organic compounds such as trichloroethylene (TCE), benzene, carbon tetrachloride, barometric pumping method has been used as an efficient method. It employs vertical flux chamber at land surface (Rossabi *et al.*, 1993).

8. Conclusion

Though all heavy metals are known to be toxic, some of them can be beneficial at low concentrations. Metal toxicity may lead to causes severe morbidity and serious mortality like consequences. Increasing bioavailability of organic nutrients in the soil as remediation agents can be achieved by addition of manure, compost, biosolids etc., which condition to increase soil fertility. Bioremediation methods can be executed both in aerobic and anaerobic conditions. However, aerobic conditions have been proven to have better remediation of metals and are faster compared to the anaerobic conditions. Improved bioremediation processes can be developed by establishing methods of isolation of microorganisms resistant to heavy metal and understanding of the remediation mechanisms, thereby to remove the pollutants. This review discussed the scope of various bioremediation techniques including microbial isolates, plant resources to remove heavy metals contaminated polluted environmental samples.

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