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Review on bioremediation and phytoremediation techniques of heavy metals in contaminated soil from dump site

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ABSTRACT

In current scenario the main problem of soil pollution is due to open disposal of municipal solid waste. Leachate generated in the dump yard will contaminate the soil by toxicity of heavy metals (Arsenic, Chromium, Lead, Cadmium, and mercury) which will pollute air, water and soil. This review article summarizes the various remediation techniques which enhances the efficiency of removal of contaminant in the environment. The most effective and promising methods to remediate the contaminated soil is by bioremediation and Phytoremediation. Bioremediation is the process/method which detoxify the heavy metals with the help of microorganism in environment. Phytoremediation process which helps to absorb the Heavy metals in the soil by using plants and trees to remediate the soil. Both of these techniques are cost effective and suitable for removing the heavy metals in the contaminated soil. This review aims to shows the factors which have affect or reduce the efficiency of remediation; microbes which are to be used for the process and enhancement for this technique have been discussed. Similarly, suggested plants used for phytoremediation extend the tolerance limit and reduce the metal accumulation in the soil. Heavy metal absorbed plants to be treated by incineration or utilization of some by-product for future eco-friendly uses.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Advanced Materials and Modern Manufacturing.

1. Introduction

With the rise of human population, urbanization and industrialization leads to generate large amount of solid waste [1]. Municipal solid wastes (MSW) are mainly produced from households, shops, restaurants, markets, public places and from commercial buildings. Contaminants occur in the form of leachate, and storing a large amount of pollutants is a common occurrence in most MSW sites. Improper disposal of solid waste create number of problems in the society mainly it affects human health hazard, impacts organisms in the soil and water also and which is harmful to the surrounding environment. Soil is considered as a significant natural component and material for individual endurance and biological system enhancement. Soil acts predominant role to infiltrate contaminants in their pathway comes from water and air [2]. Different types of organic pollutant and heavy metals are caused by MSW [3,4]. There are 5 million soil pollution sites comprising 500 million acres of land, with soils polluted by high concentration of various pollutants particularly heavy metals, with soil condition concentrations that exceed geo-baseline or regulatory standards [5]. Arsenic, copper, Cadmium, Chromium, Mercury, lead and Nickel are metals and metalloids with an atomic mass larger than 20 and a specific gravity greater than 5 [6]. Implementing safe disposal methods and developing effective soil remediation techniques are critical and required [7]. Soil remediation is the process of treating contaminated soil to recover its original state. For the cleanup of contaminated soil, various techniques are available such as physical, chemical and biological techniques are to be performed. [8]. In this review paper discuss about biological process such as bioremediation and phytoremediation. Bioremediation, a microorganism-mediated process, is a long-term solution for reducing and detoxification of environmental contaminants [9]. The aim of bioremediation is to use microbes naturally occurring catabolic ability to accelerate the transformation of pollutants in the soil environment. As a result, microbial bioremediation offers an alternative, cost-effective, and environmentally friendly technique for cleaning up contaminated soils [10]. Phytoremediation is a process which involves plants to remove or reduce the concentration of pollution

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in the contaminated soil environment [11], which involves utilizing a green plant's to remove heavy metals from soil and water also. Phytoremediation has so many advantages over the physical and chemical treatment, including cheap cost, simplicity, and environmental friendliness [12].

2. Methodology of review

See Fig. 1.

3. Bioremediation

Bioremediation is an employment of microorganisms to remove or detoxify pollutants from soil and water. The aim of bioremediation is to remediate polluted site from the environment with the help of bacteria and microbes. Bioremediation divided in to two types, they are in-situ and ex-situ contaminant removing process. In-situ bioremediation is the process of removing contaminated materials in the soil in their own location and the soil need not to be excavated and the ex-situ remediation to exhume the soil sample from the contaminated site and bring into laboratory for further analysis. The dangerous substances on the surface are cleaned using a biological treatment by bacteria multiplying which helps to breakdown organic matter from this process to delivering oxygen and nutrients to the polluted region from contaminants [13].

3.1. In-situ bioremediation

In-situ bioremediation subjected to different techniques to remediate such as Bioventing, Biosparging and Bioagumentation.

3.1.1. Bioventing technique

It's a method for degrading any aerobically degradable substance. By inoculation nutrients like either nitrogen or phosphorus along with oxygen is the process behind bioventing technique. The Soil texture is one of the factors affecting the flow of nutrients along with oxygen. However with the help of reduced airflow the microbes receive enough oxygen. To put in simple words its an process which involves the injection of air to the contaminated soil up to its water table, through air suction well [14].

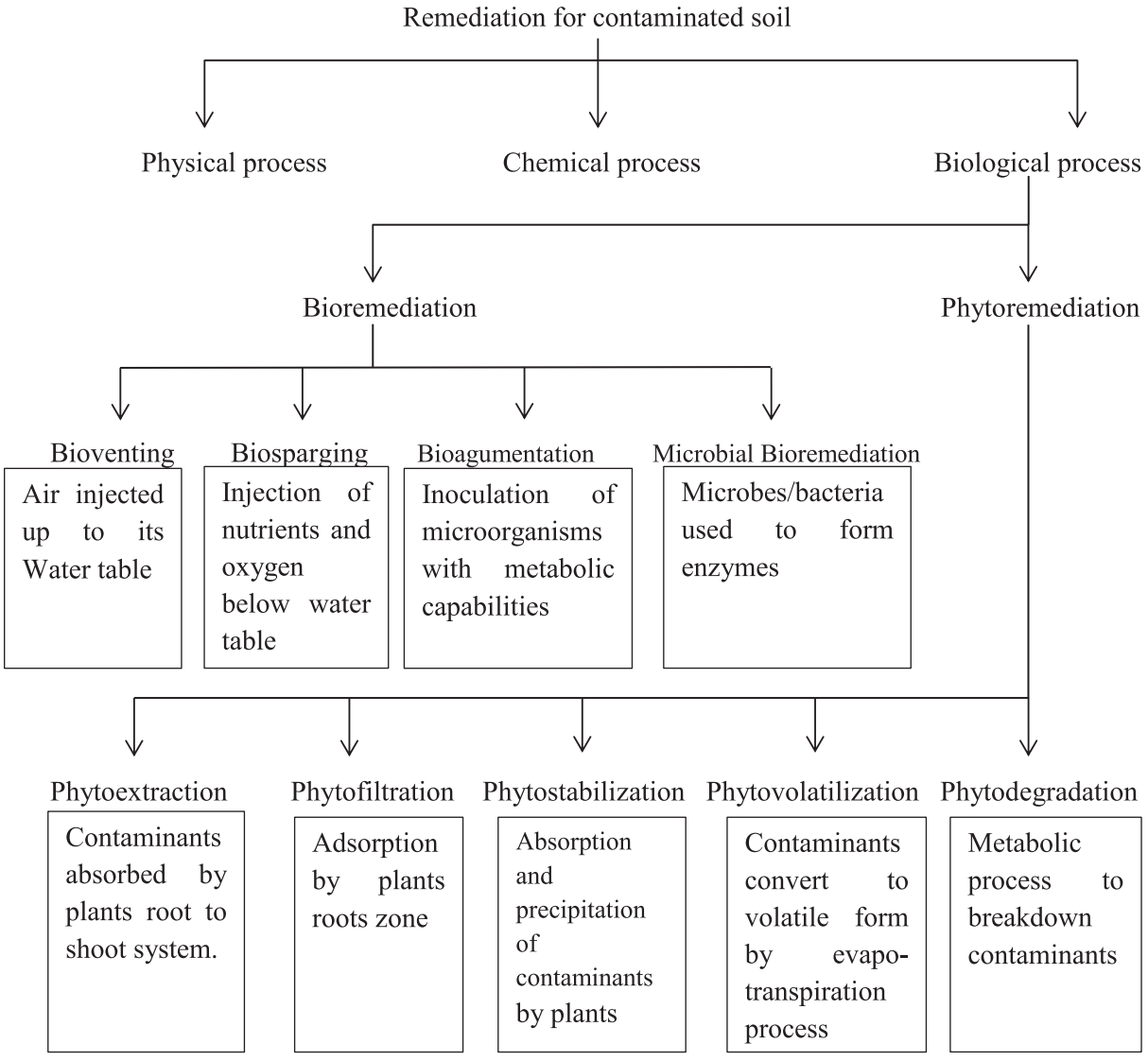


Fig. 1. Methodology of Flow Diagram.

3.1.2. Biosparging technique

The process is similar to the above one the only difference is that, here the injection of nutrients and oxygen is below the water table. There by increasing the level of oxygen concentration. This triggers the naturally available bacteria to biological degradation. This method is very feasible because of its cost and easy installation [15].

3.1.3. Bioagumentation technique

To improve waste breakdown, microorganisms with appropriate metabolic capabilities are introduced to the contaminated location. This process is suitable for soil which is contaminated by chlorines. In this method contaminant are converted into nontoxic materials completely by microbial activities [10].

3.1.4. Microbial bioremediation

Bacteria and fungi are the most common microorganisms employed to remove heavy metals from contaminated soils, however yeast and algae are also used often [16]. Bioremediation by microorganisms will be successful when single strain culture is replaced by clusters of bacterial strain [17]. Microorganisms through precipitation processes, biosorption by sequestration to their intracellular metal binding proteins, and conversion of metals to harmless forms by enzymes are all employed in heavy metal remediation from polluted soils [18]. Microbes/bacteria used for bioremediations are more than 25 genera which have great potential to degradation of MSW, some of them genera and their species are listed in Table 1.

3.2. Factors influencing bioremediation

Bioremediation is influenced various parameters, like soil properties such pH and mineral or nutrient composition, environmental factors such as climate and temperature, and also by microbial activities. More the bacteria results in significant variations in the hazardous nature of contaminates [21].

3.2.1. Nutrients supplementation

The nutrients are prime factor for growth of microorganism so supplementation of nutrients is critical aspects for proper bioremediation process which succeed the removal of contaminants in the soil. Because the organic carbon content of polluted areas is significant, these carbons may be depleted during microbial metabolism. Applying various nutrient sources to the polluted site, such as potassium, nitrogen, and phosphate, can accelerate microbial growth and increase bioremediation [19,22].

3.2.2. Temperature

Temperature plays an important role in contaminant bioremediation. The contamination level increases when there is a rise in the temperature, due the solubility of pollutants and heavy metals. Microbial actions grow in lockstep with temperature rises in the appropriate range, since it increases microorganism metabolism and enzymatic activity, speeding up the bioremediation process of contaminates. The optimum temperature for the process is range of 22–36 °C [23].

3.2.3. Microbial diversity

Microbes of various species have the ability to influence bioremediation activity. Contaminants such as heavy metals can also have an impact on microbial diversity. In addition, the microbial communities must adapt in the contaminated site. The microbes are collecting from polluted location by strains sampling technique frequently exhibit high resistance to heavy metal contamination [24].

3.2.4. pH

pH is well established to be one of the most important factors in contaminant bioremediation effectiveness. pH is negative hydrogen ion concentration denotes 0 to 14 in its relative scale [25] and has an impact on microbes, many species is found to have different optimum pH levels. The pollutants like heavy metals have a direct effect on bacterial growth and its metabolism by modifying the pH level, the amount of available oxygen levels and other environmental factors can helps in bioremediation [26].

3.3. Advantages and Limitation of different bioremediation techniques

See Table 2.

3.4. Ex-situ bioremediation

In this method the remediation implements are not carried out directly on the site, instead the polluted soil is collected and the treatments were provided at controlled environment which away from the site. The technique used for ex-situ bioremediation is biopiling, composting and landforming.

3.5. Limitation of bioremediation

Highly poisonous chemicals will have high concentration barriers to biodegradation. Due to presence of high concentration sometimes can stop microorganisms from growing or even kill them. It is necessary for proper microorganism growth to have a optimum pH and sufficient amounts of mineral nutrients, as well as a temperature where the maximum number of germs may live, in the range of 20–30 °C. If the environmental conditions are favored, the dispersal of micro-organism will help to grow at the faster are at most circumstances [15].

4. Phytoremediation

This type of bioremediation which involves flora to control the effect of pollutants present in the environment and their hazardous effects is known as phytoremediation. It works best when the contaminants are spread out over a large region and are within the plant's root zone [11,27]. The techniques used for phytoremediation are phytoextraction, phytofiltration, phytostabilization, phytovolatilization, and phytodegradation [28].

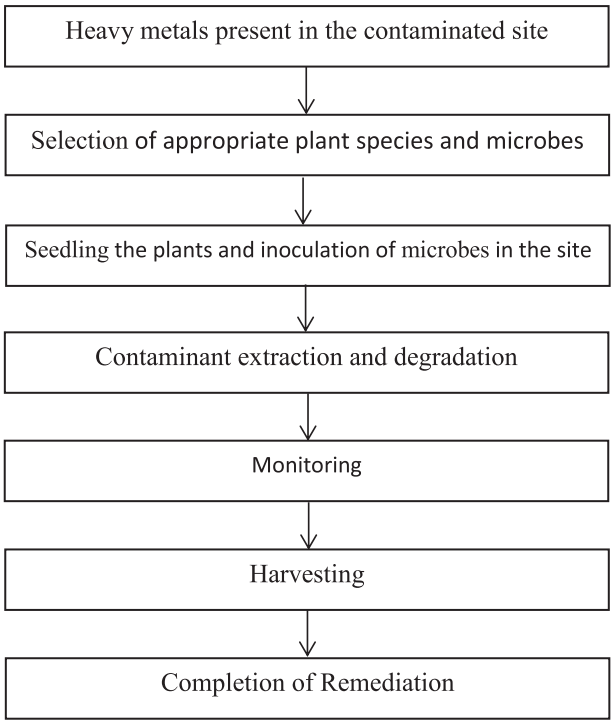
4.1. Steps involved in phytoremediation of contaminated site

Table 1
Microbes used for Bioremediation [4,19,20].

Aspergillus clavatus	Alternaria alternata	Aspergillus flavus	Aspergillus candidus	Aspergillus luchuensis
Aspergillus fumigatus	Aspergillus nidulans	Aspergillus niger	Fusarium oxysporum	Gliocladium sp.
Penicillium digitatum	Chrysosporium sp.	Aspergillus terreus	Cladosporium sp.	Curvularia lunata
Fusarium roseum	Acremonium butyri	Chaetomium sp.	Humicola sp.	Myrothecium sp.
Paecilomyces sp.	Rhizopus sp.	Sclerotium rolfsii	Drechslera sp.	Trichoderma viride

Table 2
Advantages and Limitation of different bioremediation techniques [14,15].

Sl. NO	Bioremediation Technique	Advantages	Limitations
1	Bioventing	This technique is more suitable for a water table of more depth from ground surface and it is also effective having area of high temperatures	Due to soil texture variations and composition difference, removal rate of this technique is varied.
2	Biosparging	It is easy to install and duration for treatment is very less. This technique is suitable for specific area like petroleum contaminated sites.	This technique should not be applicable to confined aquifer, air sparging (circulation) need to be uniform for biosparging.
3	Bioagumentation	Microbes will do all the work and remove the contaminants in the site; labour requirement is less, so the operating cost for this technique is very less	Suitable environment required for the microbes to thrive and it is not adopted for oil contaminated sites.



4.2. Phytoextraction

The transfer of hazardous pollutants from the contaminated soil to the various parts of the plant through its root system to transfer in shoot system is known as phyto-extraction, also known as phytoaccumulation. Hyperaccumulators are plants that absorb a disproportionately high amount of metals as compared to other plants. The selection of the plants is purely depends on the type of pollutants and soil conditions, in some cases even one or more plants also selected. These plants were fired or composted after its service life time [29].

4.3. Phytofiltration

In this method the pollutants are deposited around the root system of the plant. These plants are employed in treatment of polluted water than contaminated soil. The contaminated water from various waste sites is brought and delivered to this grown up plants. In this way the polluted water is treated by adsorption process are also called as Rhizofiltration [29].

4.4. Phytostabilization

In this process using particular type of plants which can absorb and precipitate pollutants, usually metals, lowering their bioavailability and thereby lowering the risk of human exposure. This method is helpful in recovering the natural vegetation which is affected due to high polluted concentrations present in the soil. Metal-tolerant species can be utilised to re-vegetate the areas, reducing the risk of contamination spreading by geological agencies erosion and transportation of exposed surface soils, as well as contamination leaking into groundwater [30].

4.5. Phytovolatilization

The conversion of heavy metals in to the respective volatile forms by plants (Leaves) and releasing them is known phytovolatilization. This process occurs by transpiration process and it will release the pollutants in atmosphere [28].

4.6. Phytodegradation

Phytodegradation, also known as phyto-transformation, in this method the plant metabolism helps in breakdown high pollutants either inside the plant or sometimes this breakdown occurs outside the plants. The external breakdown is carried out by the plants with the help of enzyme like substances generated by it. These pollutants after the break down are utilize as an nitrients [29].

4.7. Advantages and Limitation of different bioremediation techniques

See Table 3.

4.8. List of microorganism that assists plant growth for phytoremediation

See Table 4.

4.9. Plants used for phytoremediation

The Plants which has characteristics like fast growth, large shoot system and also the plants with high metabolism and heavy resistance to metal concentrations. Hyper accumulators have a high potential detoxifying potential due to their high absorption and effective root to branches of plants via transport system, which is gifted with higher tolerance of metal [36]. There are more than 25 plant species which removes heavy metals effectively, among some are listed in Table 5.

4.10. Effect of accumulation of heavy metal in plant

- Production of reactive oxygen species
- Displacement of essential metal ions
- Reduction in plant biomass, starch, amino acids, root and shoot system
- Affect plant growth, seedling height and affect yield of crop
- Decrease in chlorophyll content and nutrients in plants.

Table 3
Advantages and Limitation of different bioremediation technique [29,30].

SI. NO	Phytoremediation Technique	Advantages	Limitations
1	Phytoextraction	It is cost effective method and the contaminant absorbed plants are disposed by incineration hence biomass produced are more [31]	Process for remediation of soil takes too much time for high metal concentration sites [31]
2	Phytofiltration	This process will have a large root system and it will cover a large surface area to absorb the metals from contaminated site.	This technique will not suited for all contaminated sites because low level contaminated site only cleaned.
3	Phytostabilization	This technique used for the rehabilitate the indigenous ecosystem through vegetation cover and production of non-edible plants and trees.	The site is not suitable for food production after the phytostablization process.
4	Phytovolatilization	This technique is very suitable for organic pollutants and some heavy metals [32]	It will not remove all the metal concentration in the contaminated soil; it will reduce the metal concentration to some extent [32]

Table 4
Microorganism that assists Plant Growth for phytoremediation.

SI. NO	Microorganism	Explanation
1	Rhizobacteria	This microbe will resistant to plant from heavy metals accumulation and fungal affect, the rate of growth of plants will based on biomass production and stabilizing for the remediation by rizobacteria [33]
2	Ectomycorrhiza	Most dominant microorganism group to remediate the contaminated site, Pinus sylvestris is a host plant with removal of zinc with the combine action of Ectomycorrhiza [34]
3	Endophytes	Plant growth promote by nutrients supplementation of host plant, Endophytes adopted with suitable plant will remediate more effectively than any other microorganisms. Some of the endophytes microorganism are Bacillus sp, Actinobacteria sp, Consortia of bacteria, Pseudomonas sp. [35]

5. Conclusion

The most important review paper show the various types of treatment which involves in remediation of contaminated soil. Bioremediation and phytoremediation are the most significant and effective way of treatment of polluted soil,

- From the review it is clear that most of the researchers suggest that microbes based remediation methods are found to be eco-friendly and recommended for various contaminated sites which has low range of pollutions.
- In addition with, the microbes used for bioremediation matters and it leads for the improvisation of remediation from other techniques.
- Under phytoremediation technique phytovolatilization involves in treatment of contaminated soil and removal of heavy metals effectively. The plant which is more suitable for removal of more heavy metal is *Pistia stratiotes* (water cabbage).
- Soil contamination for bioremediation and phytoremediation method could be modified to provide an environmentally friendly, long-lasting, low-cost remediation system with high efficiency.
- As a result, pursuing an integrated advanced biotechnological study in the field of bioremediation is an emerging technique and is to be improved by adopting suitable conditions.

Authors contribution

Praveen R have carried out literature survey on soil bioremediation and phytoremediation. Also prepared the review article completely. Nagalakshmi R contributed in manuscript correction and reviewing to enhance the review article.

Data availability

No data was used for the research described in the article.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Table 5
Plants and microbes used for phytoremediation.

SI. No	Plant species	Microbes	Heavy metals Removal	References
1	*Pistia stratiotes* (water cabbage)	Microbacterium	Pb, Cd, Hg, Ag, Cr, Cu, Ni, and Zn	[37]
2	*Thlaspi Caerulescens* (Alpine Pennygrass)	Achromobacter piechaudii E6S [35]	Zn and CD	[38]
3	*Alyssum murale* (Yellow tuft)	Bacillus thuringiensis GDB-1 [35]	Ni	[39]
4	*Cannabis sativa* L. (Hemp)	Penicillium sp. CBRF65, Phialocephala fortinii [35]	Cd,Cu	[40]
5	*Sorghum halepense* L.(Johnson grass)	Alternaria sp. CBSF68	Pb	[41]
6	*Helianthus annuus* (Sunflower)	Alternaria sp. CBSF68 [35]	Pb	[42]
7	*Corrigiola Telephiifolia* (Corrigiola (Spanish))	Bacillus thuringiensis GDB-1	As	[43]
8	*Achillea Millefolium* (Common Yarrow)	Actinobacteria sp.,	Hg	[44]
9	*Brassica juncea* (Indian mustard)	Enterobacter sp. CBSB1	Zn	[29]
10	*Thlaspi Caerulescens* (Alpine Pennygrass)	Variovorax sp., [35]	Cd	[45]

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