BIOREMEDIATION

Abstract

Bioremediation is a new emerging technology which is used to control pollution. This technique involves microbial metabolism to degrade contaminants present in the environment. These mini-creatures may be indigenous or exogenous to the polluted site. The operation of bioremediation can be performed with either in-situ or ex-situ strategy. This chapter emphasis the basic technique and advantages of bioremediation, which makes it patronizing over to other pollution control mechanism. Various xenobiotic can be converted to non-hazard compounds by this approach. Also the phytoremediation is very effective to overcome the problem of heavy metal pollution.

Keywords: Metabolism; Indigenous; Exogenous; Xenobiotic; Phytoremediation.

Author

Shikha Shrivastava
Department of Microbiology
Government S. K. Y. College
Gunderdehi, India.
Shikhakwd001@gmail.com

I. INTRODUCTION

The problem of pollution does not arise as sudden. Since the civilization has started men has been disturbing the environment knowingly or unknowingly and creating different kinds of pollution. But now pollution is increasing vigorously in every direction. It will not hyperbola to say that today pollution is omnipresent. However, science has also developed many technologies to encounter pollution. Now we have a lot of strategies to minimize the problem of pollution. The approach we are discussing here (Bioremediation) is the most reliable one. Bioremediation; as the term indicates, reduces the pollution with the help of living being, specially the microorganisms. Bioremediation process remove the toxicity from the polluted site by providing optimum condition to microbes so that microbial growth can degrade the specific pollutant. Bioremediation immobilize organic compounds to create safer environment. Bioremediation is actually a stimulated degradation of pollutants by microbial culture. Microorganisms are well known for their degradative ability. They function as decomposer in the environment, cleave organic compounds into simpler form. Thus decomposition is the natural process in environment and Bioremediation technique enhance the efficacy of this natural phenomenon for better outcomes.

The term Bioremediation is derived from Latin word which means to cure or act or process of healing. So Bioremediation is the process of treating environmental pollution, the process of treatment of pollutants using microbes or microbial products is called Bioremediation. Microbes can use hazardous pollutants as their source of energy for their growth or they degrade these pollutants into simpler less toxic ones. Actually it is a branch of biotechnology which deals with pollution control strategies. In bioremediation process pollutants are removed or converted to less harmful compounds.

One can say that Bioremediation is a waste management strategy specially for recalcitrant, which use microorganisms to bring down the lethality of pollutants[1]. In the Bioremediation process, toxigenicity of pollutants is reduced to enhance the sustainability of our environment. Bioremediation is a selective process. The specificity of the process depends upon the type and concentration of substrate pollutants, microbes to be used and different factors that affect the microbial metabolism. The whole treatment could last for several weeks to several months. In present era Bioremediation is one of the most useful development of science to encounter the problem of pollution. Bioremediation is an effective tool for the restoration of the environment.

II. HISTORY

Bioremediation is a natural process occurring since the life has started in the Earth, but people are unaware about this. In modern age, a petroleum engineer of California, George M. Robinson was first to observe the bioremediation during his research in 1960s. He worked with microbes and various pollutants to check the degradation of pollutants.

In 1972, cleaning of oil spill at Ambler, Pennsylvania was first for w the concept of bioremediation was used on large scale for the first time, for Environmental Protection

[1] “Bioremediation of Contaminated Soils and Aquifers - Bioremediation - Wiley Online Library.”

Agency (EPA) has developed protocol for bioremediation in 1992, on the basis of different case studies.

The modern approach of bioremediation is to search novel microorganisms from contaminated sites. It is observed that these microbes have greater ability to overcome pollutants.

III. LIFE AROUND POLLUTION

Due to several anthropological activities many synthetic chemicals are being introduced in to the environment. Industrialization, deforestation use of chemicals on agriculture field and many other activities have been created the problem of pollution. Uncritical removal and improper treatment of waste has increased the problem very much. These synthetic chemicals are persistent in nature thus creating environment pollution that are even lasts for many years. The pollution not only disturb our ecosystem but also adversely affect human health. Pesticides, hydrocarbons, petroleum waste, PCB, CFC, PVC, polythene, polyester Compound, chemical fertilizers, industrial effluents, cosmetics and many more chemicals are persistent in nature. Many of these chemicals are found to be carcinogenic. Besides these organic compounds heavy metals like mercury cadmium, lead also create health issues by affecting the cellular processes.[2] Many non-heavy metals like fluorine also create health issues when these are present in above the trace level.

The pollutants are mainly discharged in water bodies and soil and few are in the atmosphere. Atmospheric gases can enter our body through respiration while other pollutants which are discharged in land and aquatic system are directly or indirectly enter to agriculture land. Therefor unfortunately soil act as sink for pollutants. In this way all food materials that we are eating like cereals, vegetables fruits, dairy products, poultry, meat and fish everything is contaminated with chemicals and are introducing little or more quantity of harmful chemicals into our bodies which creates many abnormalities in our body. [3]

Organic aromatic compounds cannot be easily degraded because of their xenobiotic character and accumulated in the environment. when these chemicals enter the bodies of living beings the aggregation of chemicals within body is called bioaccumulation[4]. The accumulated compound continually concentrated on the higher Tropic level the process is known as bio-magnification. Due to magnification pollution affect the most to the organisms that are present on higher tropic level and the lowest to the organisms on the bottom of food chain. As human are at the top of Tropic level in food chain, pollutant get concentrated in human body and affect them the most.

Effects of pollution could be study under short term and long term effects. The short term effects of pollution include bronchitis irritation to throat eyes and skin nausea dizziness diarrhea indigestion etc. short term effects induce when severe Level of pollutants r present which rapidly act on human health however, these effects are temporary and could be

---

[2] Kaur et al., “Chapter 8 - Bioremediation.”
[3] Vandana et al., “Chapter 2 - Mechanism of Toxicity and Adverse Health Effects of Environmental Pollutants.”
[4] Szynkowska, Pawlaczyk, and Maćkiewicz, “Bioaccumulation and Biomagnification of Trace Elements in the Environment.”

recovered if the pollution level will reduce and become normal. But if pollutants are continually present in the environment for long period of time it can reach at the level where it strongly affects the physiology of human and animals. Long term effects are lethal hard to cure and can lead to death of a person. It includes heart disease, lung cancer, respiratory disease, chronic Pulmonary Disorder, Endocrine Disturbance, PCOS i.e. polycystic ovary syndrome. Now PCOS is very common to young girls. Teenagers are also getting diagnosed for lung disease and other health abnormalities. In this way we can understand how dangerous the pollution is for community.

IV. WHY BIOREMEDIATION

Since the industrialization has developed pollution exploded. Expansion of pollution is nearly out of the control. The awareness for pollution and its control is one of the major program of any government in the World. Why the awareness program is needed? Why the governments are focus on the resolution of problem of pollution. This chapter is an attempt to answer all these questions.

As mentioned earlier pollution disturb the natural balance of the environment and interrupt with many natural processes. When pollution was at very low level, like before the era of industrialization, it had negligible effect. But the vigorousity of pollution is a major issue today. There is no part on the Earth that we can say is pure and free from contamination. At present time the pollution has reached at that stage that it severely affects the environment and living being including herbs, animals and human.

Environment itself tries to overcome pollution, but the natural mechanism of removing pollution is very slow and the amount of contaminants is enormous. So the natural process is unable to balance environment at its previous stage in many hundreds of years. To enhance the contaminants removing procedure many techniques have been developed. Most of these techniques have approaches that are costly and laborious. To overcome this, science has explored an easier way, that work around the natural phenomenon. Since natural process of pollutant degradation involves microbial metabolism, this new approach is basically of the modification of natural process. This new technique bioremediation is superior to conventional strategies. The approach is ecofriendly, with minimum or no harm to environment[5]. Bioremediation is basically the stimulation of natural degradation process. This restoring effect enhance the degradative ability and efficacy. This approach is catching eyes of every environment scientist.

V. IN SITU VS EX SITU

Bioremediation operation can be performed in contaminated site or another site the contamination. According to the site bioremediation can be divided into in situ and ex situ. In situ means on site and ex situ means another site. Bioremediation in in situ strategy is of low cost but many conditions move remediation toward ex situ.

[5] Azubuike, Chikere, and Okpokwasili, “Bioremediation Techniques–Classification Based on Site of Application.”

1. Low temperature of environment does not promote rapid growth of needed microorganism for bioremediation. So that the process become very slow.
2. Dense soil or soil with low porosity cannot distribute pollutants microorganisms equally therefore, the process not gives satisfactory result.
3. Large concentration of pollutants also hinders the bioremediation operation.
4. Many times overall environment like PH and chemicals present in contaminated site affect the remediation process therefore the result is not appropriate.

If any situation discussed above is present, the polluted soil or water is excavated and transported to another area where ex situ bioremediation process could be completed. The operation of ex situ bio remediation process increase cost due to excavation transportation, and controlling the environment for microbial growth. This enhanced economical input makes in situ first choice for remediation. Choice between in situ and ex situ operation is basically depend upon the concentration of pollutant chemical nature geographical location. Many new technologies are now developing in field of pollution removal by using microbes, like advanced oxidation processes (AOPs), biochar, microbial fuel cells (MFCs), and biogenic nanoparticles. Mixed phenomenon of AOPs with microbes has shown higher pollutant removal.[6]

VI. CHOICE OF MICROBES

In nature microorganisms act as fighter against environmental pollution. Various microorganisms occur in different environmental conditions that have degradation capability of many contaminants. In many cases pollutant function as source of energy and/or carbon for growth of microorganisms therefore microbes are particular in these sources. In other cases, microorganism need of carbon and energy source and they just degrade contaminants without using them. Microbes need unique nutritional sources and environment without which they cannot survive. These mini creatures are at the Base of bioremediation operation. High growth rate, adaptability and acclimatization capability make them efficient for purpose of bioremediation. Both aerobic and anaerobic microbes are studied and showed remediation ability for different compounds. Specific metabolic enzymes responsible for the degradation of contaminants. Table 1 shows the different enzymes that are used is remediation. When we want to choose microbes for bioremediation purpose, many perceptions should be remembered the most important concept to know is the metabolic pattern of microorganisms which is directly related to degradation of pollutant. many factors are responsible for selection of microbes and Operation of bioremediation.[7] Some of these factors includes.

1. **Pollutant:** All pollutants cannot be utilized by single microorganism. We should select specific microbe which can use pollutant or convert it to nontoxic form. The nature of pollutant also affects the process of remediation. Nature of pollutant includes solubility, reactivity, volatile nature, Permeability and susceptibility to enzyme.

2. **Intensity of Pollution:** It has been seen that when pollutants present in huge quantity it is hard to remove. For this Issue combination of microbial culture and microbial

[6] Ravinuthala et al., "Chapter 11 - Novel Technologies Coupling Microbes for Efficient Removal of Known, Emerging, and Unknown Pollutants in Wastewater Treatment."
[7] Seagren, "Bioremediation."

interaction can be used. However higher concentration of pollutant moves the remediation operation toward ex situ Strategy. Depth of pollution also extend the time of operation.

3. **Temperature:** In bioremediation temperature is an important factor as it greatly affects the microbial growth. For in situ operation it is necessary that the temperature of contaminated site matches the optimum temperature of microbial culture to be used. If indigenous microorganisms are not giving satisfactory result, then non negative microorganism can be added which can grow on that specific temperature. Normally in situ bioremediation can be perform between 25 to 40 degrees centigrade. Sites with lower or higher temperature are not optimum for the bioremediation in in situ therefore ex situ Strategy is applied for these regions.

4. **pH:** pH of polluted site also affects microbial growth. It is necessary to maintain the pH range at which microorganism can grow maximum. It is seen that contaminants generally lower the ph. To maintain the pH range acid or alkali can be added as required.

5. **Carbon and Energy Source:** There are many microorganisms that degrade pollutant and use them as a source of energy and carbon. They don't need another source for their nutrition. But many microorganisms cannot utilize pollutant, they just degrade them during their Physiology. These type of microorganisms require nutritional supplements to fulfill their need for growth.

6. **Presence of Inhibitor:** If any substance that can inhibit or hinder microbial growth is present on site it will abort the remediation process. To avoid this condition resistant strength should be used. It is most necessary that the pollutant which has to be treated is not hazard to microbes.

Table 1: Some Important Enzymes Associated with Bioremediation
(Husain Et Al 2009)[8]

S.N.	Enzyme	Target Pollutant
1	Aromatic dehalogenase	Chlorinated aromatics (PCBs, DDT)
2	Nitrilase	Herbicides
3	Nitroreductase	Explosives (RDX and TNT)
5	Phosphatase	Orgnophosphates
6	O-glucosyl transferase, O-malonyl transferase, Carboxyl esterase, Glutathione s-transferase, Peroxygenases, Peroxidases, N-glucosyl transferase	Xenobiotics
7	Cytochrome P450	Xenobiotics (PCBs)
8	Peroxdase	Phenols
9	O-demethylase	Alachlor, metalachor
10	Laccase	Oxidative step in degradation of explosive
11	Dehalogenase	Chlorinated solvents and Ethylene

[8] Qayyum, Maroof, and Yasha, "Remediation and Treatment of Organopollutants Mediated by Peroxidases."

VII. TECHNIQUES OF BIOREMDIATION

In today's scenario managements of polluted sites by using microbes and microbial products has proven effective and reliable approach. The bioremediation could be performed in two ways: in-situ and ex-situ, bases on the site of treatment. Fig. 1 shows different techniques of bioremediation. Both approaches have many techniques that facilitate remediation differently. These techniques are used according to pollutants, intensity of pollution and various other factors.

1. **Bioaugmentation:** Bioaugmentation techniques involoves addition of non-native microbes in contaminated sites to boost up the degradation. This in-situ strategy is used when indigenous microorganisms are not giving satisfactory results. Added microbial culture either convert pollutants into such compounds that can be easily degradaed by native microbes or they directly help in degradation by symbiosis and other microbial interactions. The technique is highly important for treatment of recalcitrants.

2. **Bioventing:** Bioventing is an in-situ bioremdiation technique that facilitate aerobic microbial degradation of contaminants. It involves controlled oxidation supply in unsaturated zone of contaminated soil. The addition of oxygen stimulates microbial activity and enhance the process of transformation. For stimulation of microbial process, nutrients can also be added, if required. This technique is becoming more popular than other in situ techniques especially for management of petrolium contaminated sites[9]. Air injection rate is the basic parameters for pollutant dispersal, redistribution and surface loss during bioventing.

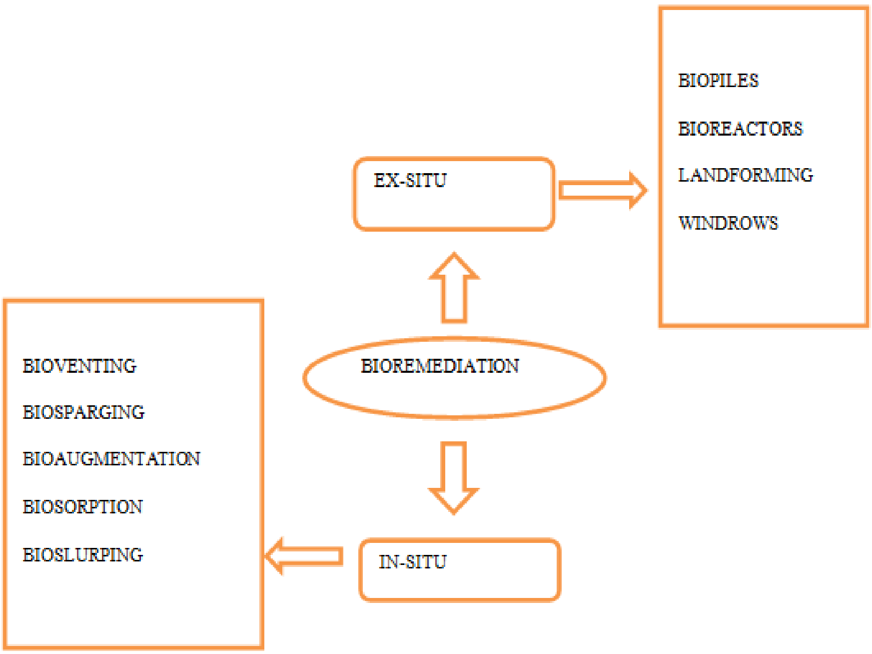

Figure 1: Various Techniques of Bioremediation

[9] Höhener and Ponsin, "In Situ Vadose Zone Bioremediation."

3. **Biosparging:** Like bioventing, biosparging also involves addition of oxygen into contaminated soil, but this strategy introduce air into saturated zone. In biosparging, air flow rate is slower to enhance aerobic degradation and minimize volatilization. The efficiency of sparging affected by soil permeability and other physical properties of soil[10]. Biosparging is majorly used to treat petrolium contaminants in waterbodies.

4. **Bioslurping:** This in-situ technique is a modification of bioventing. The strategy involves the fusion of bioventing, vaccum enhanced pumping and soil vapor extraction. This process is used to remediate soil and groundwater. The indirect stimulation of contaminant enhance biodegradation efficiency.[11] In containated field, bioslurping can also be perfored for volatile and semivolatileorganics.. The system uses a “slurp” that extends into the free product layer, which draws up liquids from this layer The components of the technique involve aeration, irrigation, nutrient and leachate collection systems, and a treatment bed.

5. **Biopiles:** Biopile-mediates bioremediation involves ex-situ remediation of burrowed polluted soil above the ground. To enhance microbial activity nutrients and aeration could be added, resulting in better remediation. The components of the biopiles technique involve aeration, irrigation, nutrients and lechate collection system, and a treatment bed. This ex situ technique is continuely concidering for treatment purpose due its properties like cost effectiveness and adequately controlled environment for bioremediation. Similarly, Dias et al. (2015) reported 71 % reduction in total hydrocarbon concentration, and a shift in bacterial structure over 50-day study period following pretreatment of contaminated soil samples prior to biopile formation, and subsequent biostimulation with fishmeal. The biopile is reported to be able to bio remediate various types of soil samples eg. Clay and sandy soil . If heating system can be incorporated into biopile design it increases microbial metabolism and availability of contaminants resulting in increase rate of remediation following the less time for degradation .

6. **Windrows**: Another ex situ bioremediation techniques, windrows demands periodic turning of piled polluted soil to enhance bioremediation. The turning of soil increases degradation activities bacterial community present in contaminated soil. The periodic turning of polluted soil addition of water introduce various effect on site i.e. increase in aeration, equal distribution of pollutants, nutrients and microbial degradative activities, thus speeding up the rate of bioremediation, which can be accomplished through assimilation, biotransformation and mineralization . Windrow treatment showed higher rate of hydrocarbon removal as compared to biopile treatment; however, the higher efficiency of the windrow towards hydrocarbon removal was due to the soil type, which was reported to be more friable . Nevertheless, soil polluted with toxic volatiles cannot be treated by this technique due to periodic turning of soil. Anaerobic zone is developed within polluted soil due to low aeration during windrow treatment; CH4 (greenhouse gas) can be released .

---

[10] Philp and Atlas, “Bioremediation of Contaminated Soils and Aquifers.”
[11] Gidarakos and Aivalioti, “Large Scale and Long Term Application of Bioslurping.”

7. **Biopiles:** Biopile-mediates bioremediation involves ex-situ remediation of burrowed polluted soil above the ground. To enhance microbial activity nutrients and aeration could be added, resulting in better remediation. The components of the biopiles technique involve aeration, irrigation, nutrients and lechate collection system, and a treatment bed. This ex situ technique is continuely concidering for treatment purpose due its properties like cost effectiveness and adequately controlled environment for bioremediation.[12] Similarly, Dias et al. (2015) reported 71 % reduction in total hydrocarbon concentration, and a shift in bacterial structure over 50-day study period following pretreatment of contaminated soil samples prior to biopile formation, and subsequent biostimulation with fishmeal. The biopile is reported to be able to bio remediate various types of soil samples eg. Clay and sandy soil[13]. If heating system can be incorporated into biopile design it increases microbial metabolism and availability of contaminants resulting in increase rate of remediation following the less time for degradation[14].

8. **Windrows:** Another ex situ bioremediation techniques, windrows demands periodic turning of piled polluted soil to enhance bioremediation. The turning of soil increases degradation activities bacterial community present in contaminated soil. The periodic turning of polluted soil addition of water introduce various effect on site i.e. increase in aeration, equal distribution of pollutants, nutrients and microbial degradative activities, thus speeding up the rate of bioremediation, which can be accomplished through assimilation, biotransformation and mineralization[15]. Windrow treatment showed higher rate of hydrocarbon removal as compared to biopile treatment; however, the higher efficiency of the windrow towards hydrocarbon removal was due to the soil type, which was reported to be more friable[16]. Nevertheless, soil polluted with toxic volatiles cannot be treated by this technique due to periodic turning of soil. Anaerobic zone is developed within polluted soil due to low aeration during windrow treatment; CH4 (greenhouse gas) can be released[17].

9. **Bioreactors*:*** Bioreactor is also an ex situ bioremediation strategy in which specific pollutants a are converted to specific product(s) by series of biological reactions in a big vessel called bioreactor. The choice of operating mode depends mostly on market economy and capital expenditure. Conditions in a bioreactor support the microbial metabolism by providing optimum growth conditions. Polluted samples can be fed into a bioreactor in the form of dry matter or slurry. Excellent control of growth parameters (temperature, pH, agitation and aeration rates, substrate and inoculum concentrations) is the most advantageous feature of bioreactor-based bioremediation. This ability can be effectively used to reduce bioremediation time of bioremediation. Maximum biological degradation can be achieved with minimum abiotic losses due to flexible nature of bioreactors .

---

[12] Whelan et al., "Fate and Transport of Petroleum Hydrocarbons in Engineered Biopiles in Polar Regions."
[13] Chemlal et al., "Modeling and Qualitative Study of Diesel Biodegradation Using Biopile Process in Sandy Soil."
[14] Aislabie, Saul, and Foght, "Bioremediation of Hydrocarbon-Contaminated Polar Soils."
[15] Barr, *Biological Methods for Assessment and Remediation of Contaminated Land*.
[16] Coulon et al., "When Is a Soil Remediated?"
[17] Hobson, Frederickson, and Dise, "CH4 and N2O from Mechanically Turned Windrow and Vermicomposting Systems Following In-Vessel Pre-Treatment."

10. **Bioreactors:** Bioreactor is also an ex situ bioremediation strategy in which specific pollutants a are converted to specific product(s) by series of biological reactions in a big vessel called bioreactor. The choice of operating mode depends mostly on market economy and capital expenditure. Conditions in a bioreactor support the microbial metabolism by providing optimum growth conditions. Polluted samples can be fed into a bioreactor in the form of dry matter or slurry. Excellent control of growth parameters (temperature, pH, agitation and aeration rates, substrate and inoculum concentrations) is the most advantageous feature of bioreactor-based bioremediation. This ability can be effectively used to reduce bioremediation time of bioremediation. Maximum biological degradation can be achieved with minimum abiotic losses due to flexible nature of bioreactors[18].

11. **Landfarming:** Out of all strategies Land farming is the simplest. It is of low cost and less equipment is required for operation. The technique can be performed in either in situ or ex situ according to depth of pollution however it is more common for ex-situ strategy. In land farming, polluted soil is regularly excavated and tilled and site of treatment speciously regulates the type of bioremediation. Generally, polluted soil is excavated and carefully applied on a fixed layer support above the ground surface to allow aerobic biodegradation of pollutant by autochthonous microorganisms [19] . land farming bioremediation technique is very simple to design and implement with low capital input requirements. Also it can be used to treat large volume of polluted soil with minimal environmental impact and energy requirement. Land farming is normally used for remediation of sites polluted with hydrocarbon[20]. The biodegradation and volatilization are the two remediation mechanisms that are used in pollutant removal. Land farming system needs to be complied with government regulations, and can be used in any climate and location[21].

VIII. PHYTOREMEDIATION

Phytoremediation is a special removal of contaminants using plants and their related microorganisms[22]. Which gives best result for removal of heavy metals from polluted site. In polluted site specially for soil PABR i.e. Phyto Assistant Bioremediation strategy could be more successful that relies upon plants and rhizosphere microorganisms. This bioremediation technique requires more attention and research for greater successful outcome. Plants based remediation process involves stabilization, extraction, degradation, or volatilization of pollutants. [23] Knowledge of processes that affect availability of pollutants, rhizosphere phenomenonn, pollutant uptake, translocation, chelation, degradation, and volatilization is necessary to enhance the efficiency of phytoremediation.
Plants can also be used to treat organic contaminats in the root zone, the treatment includes

[18] Mohan et al., "Degradation of Chlorpyrifos Contaminated Soil by Bioslurry Reactor Operated in Sequencing Batch Mode."
[19] Paudyn et al., "Remediation of Hydrocarbon Contaminated Soils in the Canadian Arctic by Landfarming."
[20] Silva-Castro et al., "Response of Autochthonous Microbiota of Diesel Polluted Soils to Land-Farming Treatments."
[21] Koul and Taak, "Ex Situ Soil Remediation Strategies."
[22] Pilon-Smits, "Phytoremediation."
[23] Breton-Deval et al., "Chapter 13 - Role of Rhizosphere Microbiome during Phytoremediation of Heavy Metals."

accumulation, metabolism of organic contaminants, and encourage microbial degradation of organic contaminants.

Various plant species like Brassica, Pteris vittata, Water lettuce, Sedum alfredii and many more are reported to be useful in phytoremediation. Widespread utilization of phytoremediation is limited due to the narrow habitat range or plant's size expressing remediation potential[24]. There are only few native plant species that can tolerate, detoxify, and accumulate pollutants, which is also a barrier in field of phytoremediation. A better understanding and appreciation of the potential mechanisms for removing contaminants from the root zone and the interaction between plants, microbes, and contaminants is needed for expansion of the application of phytoremediation to additional contaminated sites.

Table 2: Plant Species Suitable for Revegitation of Mine Spoils (Prasad 2007)[25]

Mine Spoil Category	Suitable Plants Species
Bauxite mined area of Madhya Pradesh	Grevillea pteridifolia, Eucalyptus camaldll lenis, Shorea robusta
Rock-phosphate mine spoils of Musoorie	Pennisetum purpureum, Saccharum spontaneum, Vitex negundo, Rumes hastatus, Mimosa himalayana, Buddlea asiatica, Dalbergia sissoo, Acacia catechu, Leucaena leucocephela, Salix letrasperma etc.
Iron ore wastes of Orissa	Leucaena leucocephala
Haematite, magnetite, manganese spoil from Karnataka	Albizia lebeck
Lime stone mine spoils of outer Himalayas	Salix tetrasperma, Leucaena lellcocephala, Bauhinia retusa, Acacia catechu, Ipomea cornea, Eulaliopsis binata, Chrysopogon fulvus, Arllndo donax, Agave americana, Pennisetum purpureum, Erythrina subersosa
Mica, copper, tungiston, marble, dool, mite, limestone, and mine spoils of Rajasthan	Acacia tortilis. Prosopis juliflora, Acacia Senegal, Salvadora oleodes, Tamarix articulata. Zizyphus nummularia, Grewia tenax, Cenchrus setigerus. Cymbopogon, Cynodon dactylon. Sporobollis marginatus D. annlllalum
Coal mine spoils of Madhya Pradesh	Eucalyptus hybrid, Eucalyptus camaldulensis, Acacia aurifuliformis, Acacia nilotica, Dalbergia sissoo, Pongamia pinnata
Lignite mine spoils of Tamil Nadu	Eucalyptus species, Leucaena leucocephala, Acacia and Agave

[24] Arthur et al., "Phytoremediation—An Overview."
[25] Prasad, "Phytoremediation in India."

IX. ADVANTAGES OF BIOREMEDIATION

To control environment pollution there are various techniques. Many of these techniques and their combinations have been using to overcome the pollution. Out of all strategies, bioremediation displays lots of merits that make it advantageous over others. Some of these are discussed here:

1. The process of bioremediation is based on microbial metabolism therefore it is less depending upon equipment. The success can be achieved in minimum resources.
2. Bioremediation using in-situ strategy doesn't require any special site. In-situ remediation is performed in affected area. Polluted site itself provide conditions for biodegradation of contaminants. In most cases microbes present in site, seems to be satisfactory in conversion of pollutants into less-toxic ones. If indigenous microbes are not adequate for remediation exogenous microbes can be used.
3. Bioremediation hardly utilizes any laborious process. It does not work with much man power and mechanical processes.
4. Unlike conventional processes of pollution control, bioremediation is eco-friendly. It does not disturb environment at any step. The polluted site is not affected during the process except that hazards are removed; this improves the site standard.
5. Because the process utilizes less resources and labor, it does not involve much economical stress. Bioremediation operation is cheaper and cost effective so that it can be easily performed for wide area.
6. Besides conventional process of pollution control, bioremediation is near to natural process with little modifications.
7. It is superior because it not just removes toxic chemicals from contaminated sites but decompose it up to the nontoxic level.
8. Bioremediation is noninvasive in nature therefore it can carry out for long duration without creating any negative impact on environment.

All these edges furnish the importance of bioremediation over conventional strategies. These entire points are the answers of question that usually rise why bioremediation?

X. LIMITATIONS OF BIOREMEDIATION

As it says everything comes with both positive and negative sites, bioremediation too. Besides all merits given above bioremediation has its own limitations. The major limitations are discussed here:

1. In bioremediation, decomposition of pollutant is depending upon microbial metabolism which require specific growth condition. So the physical condition during the remediation should be appropriate. Any alteration in optimum growth condition can affect the process and result as well.
2. Bioremediation operation takes much time to detoxify the contaminated site. The process is lengthy and time taking.
3. If pollutant cannot be used by microorganism as a source of energy/ carbon, similar source must be added for growth. This addition of nutrients increases the cost of operation.

4. In ex situ operation, excavation and transport of polluted soil or water enhance the cost.
5. Since all microorganisms cannot utilize all compounds, the process is very specific. Bioremediation require prior knowledge of chemical nature of contaminant and microbial metabolism.
6. If intermediate product is generated during the remediation, there is a chance of its toxicity. Which is a rare case.

The limitations specified above is just a formality, because when we scrutinize the major properties of bioremediation, there are huge advantages so that little demerits can be ignored. The benefits of bioremediation is major factor which propose its dominance over other pollution control strategies. However recent technology need study and research to amplify the efficiency of remediation. The points discussed here are not disadvantages of bioremediation, these are the check points under which bioremediation could be complete.

XI. CONCLUSION

For control of environment pollution, bioremediation is known to be safer, ecofriendly and sustainable technology. it purely depends upon microbial physiology and metabolism. The process of bioremediation can be performed either on site without creating much disturbance to human activities and environment or another site from polluted area, if needed for the treatment. so the process of remedy utilize functioning of various microorganisms i.e. Bacteria, fungi, algae etc. As we know different environmental factors affect the growth and metabolism of microbes therefore they also influence the efficiency of remediation as well as outcome of the treatment. the physical environment can also cause extension of the treatment process. However, microorganism are natural decomposers, day do their work with their potential. but this natural phenomenon is very slow. For this reason, this process bears the avoidance of scientist as a treatment process and instead of microorganisms many conventional methods have been using to reduce pollutants from environment. these conventional methods are costly, laborious and have some disadvantages. All the demerits of conventional methods is encouraging attention toward natural phenomena. Now the natural remediation process is altered to accomplish success of treatment. This modified natural phenomena is taking advantage over all traditional processes because of its simplicity ease of doing and ecofriendly nature. In today’s age of industrialization, many pollutants are incorporated into the environment, affecting environment and living organisms. For different types of pollutant and chemicals various technologies are used to achieve best result. The choice of technique to be used is depend upon the type and intensity of pollutant, microbial culture, and physical environment. indigenous or exogenous microbes can be used as for the requirement of the operation. By the process of bioremediation xenobiotic and toxic compounds are converted to less harmful or nontoxic one. Also during the treatment neither harmful substance are release nor the process interrupt the environment. Application of bioremediation is taking interest of government of many developed and developing countries are also facilitating the strategy for resolving the pollution issues. The emerging technology has great advantage over conventional treatment.

REFERENCES

[1] "Bioremediation of Contaminated Soils and Aquifers - Bioremediation - Wiley Online Library." Accessed July 30, 2023. https://onlinelibrary.wiley.com/doi/abs/10.1128/9781555817596.ch5.

[2] Aislabie, Jackie, David J. Saul, and Julia M. Foght. "Bioremediation of Hydrocarbon-Contaminated Polar Soils." *Extremophiles* 10, no. 3 (June 1, 2006): 171–79. https://doi.org/10.1007/s00792-005-0498-4.

[3] Arthur, Ellen L., Pamela J. Rice, Patricia J. Rice, Todd A. Anderson, Sadika M. Baladi, Keri L. D. Henderson, and Joel R. Coats. "Phytoremediation—An Overview." *Critical Reviews in Plant Sciences* 24, no. 2 (March 1, 2005): 109–22. https://doi.org/10.1080/07352680590952496.

[4] Azubuike, Christopher Chibueze, Chioma Blaise Chikere, and Gideon Chijioke Okpokwasili. "Bioremediation Techniques–Classification Based on Site of Application: Principles, Advantages, Limitations and Prospects." *World Journal of Microbiology and Biotechnology* 32, no. 11 (September 16, 2016): 180. https://doi.org/10.1007/s11274-016-2137-x.

[5] Barr, D., ed. *Biological Methods for Assessment and Remediation of Contaminated Land: Case Studies*. CIRIA C 575. London: CIRIA, 2002.

[6] "Bioremediation of Contaminated Soils and Aquifers - Bioremediation - Wiley Online Library." Accessed July 30, 2023. https://onlinelibrary.wiley.com/doi/abs/10.1128/9781555817596.ch5.

[7] Qayyum, Husain, Husain Maroof, and Kulshrestha Yasha. "Remediation and Treatment of Organopollutants Mediated by Peroxidases: A Review." *Critical Reviews in Biotechnology* 29, no. 2 (June 1, 2009): 94–119. https://doi.org/10.1080/07388550802685306.

[8] Breton-Deval, L., A. Guevara-García, K. Juarez, P. Lara, D. Rubio-Noguez, and E. Tovar-Sanchez. "Chapter 13 - Role of Rhizosphere Microbiome during Phytoremediation of Heavy Metals." In *Microbial Biodegradation and Bioremediation (Second Edition)*, edited by Surajit Das and Hirak Ranjan Dash, 263–91. Elsevier, 2022. https://doi.org/10.1016/B978-0-323-85455-9.00016-3.

[9] Chemlal, R., N. Abdi, H. Lounici, N. Drouiche, A. Pauss, and N. Mameri. "Modeling and Qualitative Study of Diesel Biodegradation Using Biopile Process in Sandy Soil." *International Biodeterioration & Biodegradation* 78 (March 1, 2013): 43–48. https://doi.org/10.1016/j.ibiod.2012.12.014.

[10] Coulon, Frédéric, Mohammed Al Awadi, William Cowie, David Mardlin, Simon Pollard, Colin Cunningham, Graeme Risdon, Paul Arthur, Kirk T. Semple, and Graeme I. Paton. "When Is a Soil Remediated? Comparison of Biopiled and Windrowed Soils Contaminated with Bunker-Fuel in a Full-Scale Trial." *Environmental Pollution* 158, no. 10 (October 1, 2010): 3032–40. https://doi.org/10.1016/j.envpol.2010.06.001.

[11] Gidarakos, E., and M. Aivalioti. "Large Scale and Long Term Application of Bioslurping: The Case of a Greek Petroleum Refinery Site." *Journal of Hazardous Materials*, Pollution Prevention and Restoration of the Environment, 149, no. 3 (November 19, 2007): 574–81. https://doi.org/10.1016/j.jhazmat.2007.06.110.

[12] Hobson, A. M., J. Frederickson, and N. B. Dise. "CH4 and N2O from Mechanically Turned Windrow and Vermicomposting Systems Following In-Vessel Pre-Treatment." *Waste Management*, 1st UK Conference and Exhibition on Biodegradable and Residual Waste Management, 25, no. 4 (January 1, 2005): 345–52. https://doi.org/10.1016/j.wasman.2005.02.015.

[13] Höhener, Patrick, and Violaine Ponsin. "In Situ Vadose Zone Bioremediation." *Current Opinion in Biotechnology*, Energy biotechnology • Environmental biotechnology, 27 (June 1, 2014): 1–7. https://doi.org/10.1016/j.copbio.2013.08.018.

[14] Kaur, Sukhchain, Tushar Midha, Harkomal Verma, Rasmi Ranjan Muduli, Oyindril Dutta, Omprakash Saini, Richa Prakash, Sandeep Sharma, Anil K. Mantha, and Monisha Dhiman. "Chapter 8 - Bioremediation: A Favorable Perspective to Eliminate Heavy Metals from Polluted Soil." In *Metagenomics to Bioremediation*, edited by Vineet Kumar, Muhammad Bilal, Sushil Kumar Shahi, and Vinod Kumar Garg, 209–30. Developments in Applied Microbiology and Biotechnology. Academic Press, 2023. https://doi.org/10.1016/B978-0-323-96113-4.00030-5.

[15] Koul, Bhupendra, and Pooja Taak. "Ex Situ Soil Remediation Strategies." In *Biotechnological Strategies for Effective Remediation of Polluted Soils*, edited by Bhupendra Koul and Pooja Taak, 39–57. Singapore: Springer, 2018. https://doi.org/10.1007/978-981-13-2420-8_2.

[16] Mohan, S. Venkata, K. Sirisha, N. Chandrasekhara Rao, P. N. Sarma, and S. Jayarama Reddy. "Degradation of Chlorpyrifos Contaminated Soil by Bioslurry Reactor Operated in Sequencing Batch Mode: Bioprocess Monitoring." *Journal of Hazardous Materials* 116, no. 1 (December 10, 2004): 39–48. https://doi.org/10.1016/j.jhazmat.2004.05.037.

[17] Paudyn, Krysta, Allison Rutter, R. Kerry Rowe, and John S. Poland. "Remediation of Hydrocarbon Contaminated Soils in the Canadian Arctic by Landfarming." *Cold Regions Science and Technology*, Fifth

International Conference on Contaminants in Freezing Ground, 53, no. 1 (June 1, 2008): 102–14. https://doi.org/10.1016/j.coldregions.2007.07.006.
[18] Philp, Jim C., and Ronald M. Atlas. "Bioremediation of Contaminated Soils and Aquifers." In *Bioremediation*, 139–236. John Wiley & Sons, Ltd, 2005. https://doi.org/10.1128/9781555817596.ch5.
[19] Pilon-Smits, Elizabeth. "Phytoremediation." *Annual Review of Plant Biology* 56, no. 1 (2005): 15–39. https://doi.org/10.1146/annurev.arplant.56.032604.144214.
[20] Ravinuthala, Srinithya, Dhanashree Vijayrao Bomle, H. N. Sindhu, Asha Kiran, Archana, and Saprativ P. Das. "Chapter 11 - Novel Technologies Coupling Microbes for Efficient Removal of Known, Emerging, and Unknown Pollutants in Wastewater Treatment." In *Synergistic Approaches for Bioremediation of Environmental Pollutants : Recent Advances and Challenges*, edited by Riti Thapar Kapoor and Maulin P. Shah, 199–225. Developments in Applied Microbiology and Biotechnology. Academic Press, 2022. https://doi.org/10.1016/B978-0-323-91860-2.00009-9.
[21] Seagren, Eric A. "Bioremediation." In *Reference Module in Biomedical Sciences*. Elsevier, 2023. https://doi.org/10.1016/B978-0-12-824315-2.00413-9.
[22] Silva-Castro, Gloria Andrea, Imane Uad, Alfonso Rodríguez-Calvo, Jesús González-López, and Concepción Calvo. "Response of Autochthonous Microbiota of Diesel Polluted Soils to Land-Farming Treatments." *Environmental Research* 137 (February 1, 2015): 49–58. https://doi.org/10.1016/j.envres.2014.11.009.
[23] Vandana, Monika Priyadarshanee, Uma Mahto, and Surajit Das. "Chapter 2 - Mechanism of Toxicity and Adverse Health Effects of Environmental Pollutants." In *Microbial Biodegradation and Bioremediation (Second Edition)*, edited by Surajit Das and Hirak Ranjan Dash, 33–53. Elsevier, 2022. https://doi.org/10.1016/B978-0-323-85455-9.00024-2.
[24] Prasad, M. N. V. "Phytoremediation in India." In *Phytoremediation: Methods and Reviews*, edited by Neil Willey, 435–54. Methods in Biotechnology. Totowa, NJ: Humana Press, 2007. https://doi.org/10.1007/978-1-59745-098-0_30.
[25] Whelan, M. J., F. Coulon, G. Hince, J. Rayner, R. McWatters, T. Spedding, and I. Snape. "Fate and Transport of Petroleum Hydrocarbons in Engineered Biopiles in Polar Regions." *Chemosphere* 131 (July 1, 2015): 232–40. https://doi.org/10.1016/j.chemosphere.2014.10.088.

