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Review Paper

A Review on: Bioremediation

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Abstract—*A brief outline of the development of bioremediation technologies is presented. The major features and limitations are presented and an overview of the current state of the art in the field applications is sketched. The term bioremediation has been introduced to describe the process of using biological agent to remove toxic waste from environment. Bioremediation is the most effective management tool to manage the polluted environment and recover contaminated soil. Bioremediation, both in situ and ex-situ have also enjoyed strong scientific growth, in part due to the increased use of natural attenuation, since most natural attenuation is due to biodegradation. Bioremediation and natural attention are also seen as a solution for emerging contaminant problems. Microbes are very helpful to remediate the contaminated environment. Number of microbes including aerobes, anaerobes and fungi are involved in bioremediation process.*

Keywords: Bioremediation, Biotechnology, Microbes, and Carbon Sequestration**.**

Introduction

Intensification of agriculture and manufacturing industries has resulted in increased release of a wide range of xenobiotic compounds to the environment. Excess loading of hazardous waste has led to scarcity of clean water and disturbances of soil thus limiting crop production [1]. Bioremediation uses biological agents, mainly microorganisms i.e. yeast, fungi or bacteria to clean up contaminated soil and water [2]. This technology relies on promoting the growth of specific micro flora or microbial consortia that are indigenous to the contaminated sites that are able to perform desired activities [3]. Establishment of such microbial consortia can be done in several ways e.g. by promoting growth through addition of nutrients, by adding terminal electron acceptor or by controlling moisture and temperature conditions [16, 3, 5]. In bioremediation processes, microorganisms use the contaminants as nutrient or energy sources [16, 3, 6].

The population explosion in the world has resulted in an increase in the area of polluted soil and water. As the number of people continues increasing day by day it also brings with it a growing pressure on our natural resources i.e. air, water and land resources. In order to outfit to the demands of the people, the rapid expansion of industries, food, health care, vehicles, etc. is necessary. But it is very difficult to maintain the quality of life with all these new developments, which are unfavorable to the environment in which we live, if proper management is not applied. In nature there are various fungi, bacteria and microorganisms that are constantly at work to break down organic compounds but the question arises when pollution occurs, who will do this clean up job? Since the quality of life is inextricably linked to the overall quality of the environment, global attention has been focused on ways to sustain and preserve the environment. This endeavor is possible by involving biotechnology. The types of contaminants that environmental Biotechnology investigators have expertise with include chlorinated solvents, petroleum hydrocarbons, polynuclear aromatic hydrocarbons, ketones, TNT, inorganic nitrogen (NO_3, NH_4), Tt, Pu, Np, Cr, U and other heavy metals. Bioremediation is the term used to describe biological strategies applicable to repair of damaged environment using biological factors. In the case of oil spills, the process exploits the catabolic ability of microorganism feeding on oil. Several workers[7,8,9,10,11,12,13,14,15,16] have described various application of microorganism in the bioremediation of oil pollution with encouraging results.

The bioremediation and natural attenuation area has both basic research and field application foci for the environmental biotechnology. The basic research foci are co metabolism, bio-treatability, biotransformation kinetics, and modeling of biogeochemical processes. The field application foci are co metabolic techniques, biogeochemical assessment techniques, and modeling of attenuation and environmental fate [17]. Bioremediation can be defined as any process that uses microorganisms or their enzymes to return the environment altered by contaminants to its original condition. Bioremediation may be employed in order to attack specific contaminants, such as chlorinated pesticides that are degraded by bacteria, or a more general approach may be taken, such as oil spills that are broken down using multiple techniques including the addition of fertilizer to facilitate the decomposition of crude oil by bacteria. Not all contaminants are readily treated through the use of bioremediation; Heavy metals such as cadmium and lead are not readily absorbed or captured by organisms [18]. The integration of metals such as mercury into the food chain may make things worse as organism bioaccumulate these metals. However, there are a number of advantages to bioremediation, which may be employed in areas which cannot be reached easily without excavation. The foundation of bioremediation has been the natural ability of microorganisms to degrade organic compounds. Bioremediation is not a panacea but rather a natural process alternative to such methods as incineration, catalytic destruction, the use of adsorbents, and the physical removal and subsequent destruction of pollutants. The cost of moving and incinerating pollutants is at least ten times that of in situ biological treatment. By integrating proper utilization of natural or modified microbial capabilities with appropriate engineering designs to provide suitable growth environments, bioremediation can be successful in the field. However, a gap exists between advances in laboratory research and commercial field applications. Two major factors responsible for this gap are the lack of a sufficient knowledge base to accurately predict pollutant degradation rates and fates and sites designated as field research centers for bioremediation research and technology demonstrations. Laboratory and microcosm studies have documented the potential use of microorganisms for bioremediation. However, the physiologic potential of microbial populations to remediate environments of relevant size, heterogeneity and variability has not been adequately tested. Successful application of bioremediation techniques must address both the heterogeneous nature of many contaminated waste sites and the complexity of using living organisms. There has been progress in overcoming some of the barriers that have impeded bioremediation from being successfully applied in the field. Scientists have to put their efforts to search for organisms with better biodegradation kinetics for a variety of contaminants within broad environmental habitats. Studies examining extremophiles could result in using organisms in situ that have a high tolerance for organic solvents and alkaline soils or waters and that function at high temperatures for more efficient ex situ activity in bioreactors.

Biotechnology in Pollution Management

Biotechnology can be applied to assess the well being of ecosystems, transform pollutants into benign substances, generate biodegradable materials from renewable sources and develop environmentally safe manufacturing and disposal processes. Biotechnology utilizes the application of genetic engineering to improve the efficiency and cost, which are key factors in the future widespread exploitation of microorganisms to reduce the environmental burden of toxic substances. Keeping in view of the urgent need of a most efficient environmental biotechnological process, researchers have devised a technique called bioremediation, which is an emerging approach to rehabilitating areas contaminated by pollutants or otherwise damaged through ecosystem mismanagement. Bioremediation applies living microorganisms to degrade environmental pollutants or to prevent pollution or it is a technology for removing pollutants from the environment thus restoring the original natural surroundings and preventing further pollution. The rapid expansion and increasing sophistication of the chemical industries in the last century has meant that there has been increasing levels of complex toxic effluents being released into the environment [18]. Many major incidents have occurred in the past which reveal the necessity to prevent the escape of effluents into the environment, such as the Exxon Valdez oil spill, the Union Carbide (Dow) Bhopal disaster, large-scale contamination of the Rhine River, the progressive deterioration of the aquatic habitats and conifer forests in the Northeastern US, Canada and parts of Europe, or the release of radioactive material in the Chernobyl accident, etc. The conventional techniques used for remediation have been to dig up contaminated site and remove it to a landfill, or to cap and contain the contaminated areas of a site. The methods have some drawbacks. The first method simply moves the contamination elsewhere and may create significant risks in the excavation, handling, and transport of hazardous material. Additionally, it is very difficult and increasingly expensive to find new landfill sites for the final disposal of the material. The cap and contain method is only an interim solution since the contamination remains on site, requiring monitoring and maintenance of the isolation barriers long into the future, with all the associated costs and potential liability. A better approach than these traditional methods is to completely destroy the pollutants if possible, or at least to transform them to innocuous substances. Some technologies that have been used are high temperature incineration and various types of chemical decomposition. Bioremediation is an option that offers the possibility to destroy or render harmless various contaminants using natural biological activity [19]. As such, it uses relatively low-cost, low technology techniques, which generally have a high public acceptance and can often be carried out on site. It will not always be suitable, however, as the range of contaminants on which it is effective is limited, the time scales involved are relatively long and the residual contaminant levels achievable may not always be appropriate. Although the methodologies employed are not technically complex, considerable experience and expertise may be required to design and implement a successful bioremediation program, due to the need to thoroughly assess a site for suitability and to optimize conditions to achieve a satisfactory result. Because bioremediation give the impression a good alternative to conventional clean-up technologies research in this field. Bioremediation has been used at a number of sites worldwide, including Europe, with varying degrees of success. Techniques are improving as greater knowledge and experience are gained and there is no doubt that bioremediation has great potential for dealing with certain types of site contamination. Unfortunately, the principles, techniques, advantages and disadvantages of bioremediation are not widely known or understood, especially among those who will have to deal directly with bioremediation proposals, such as site owners and regulators

Principles of Bioremediation

Environmental biotechnology is not a new field, composting and wastewater treatments are familiar examples of old environmental biotechnologies. However, recent studies in molecular biology and ecology offer opportunities for more efficient biological processes. Notable accomplishments of these studies include the clean-up of polluted water and land areas.

Bioremediation is defined as the process whereby organic wastes are biologically degraded under controlled conditions to an innocuous state or to levels below concentration limits established by regulatory authorities [20].

By definition, bioremediation is the use of living organisms, primarily microorganisms to degrade the environmental contaminants into less toxic forms. It uses naturally occurring bacteria and fungi or plants to degrade or detoxify substances hazardous to human health and/or the environment. The microorganisms may be indigenous to a contaminated area or they may be isolated from elsewhere and brought to the contaminated site. Contaminant compounds are transformed by living organisms through reactions that take place as a part of their metabolic processes. Biodegradation of a compound is often a result of the actions of multiple organisms. When microorganisms are imported to a contaminated site to enhance degradation we have a process known as bioaugmentation.

For bioremediation to be effective, microorganisms must enzymatically attack the pollutants and convert them to harmless products. As bioremediation can be effective only where environmental conditions permit microbial growth and activity, its application often involves the manipulation of environmental parameters to allow microbial growth and degradation to proceed at a faster rate.

Like other technologies, bioremediation has its limitations. Some contaminants, such as chlorinated organic or high aromatic hydrocarbons, are resistant to microbial attack. They are degraded either slowly or not at all, hence it is not easy to predict the rates of clean-up for a bioremediation exercise, there are no rules to predict if a contaminant can be degraded. Bioremediation techniques are typically more economical than traditional methods such as incineration and some pollutants can be treated on site, thus reducing exposure risks for clean-up personnel, or potentially wider exposure as a result of transportation accidents. Since bioremediation is based on natural attenuation the public considers it more acceptable than other technologies.

Most bioremediation systems are run under aerobic conditions, but running a system under anaerobic conditions [21] may permit microbial organisms to degrade otherwise recalcitrant molecules. See Table 1 for a list of contaminants potentially suitable for bioremediation.

Microbial Populations for Bioremediation Process

The control and optimization of bioremediation processes is a complex system of many factors. These factors include: the existence of a microbial population capable of degrading the pollutants, the availability of contaminants to the microbial population, the environment factors (type of soil, temperature, pH, the presence of oxygen or other electron acceptors, and nutrients).

Microorganisms can be isolated from almost any environmental conditions. Microbes will adapt and grow at subzero temperatures, as well as extreme heat, desert conditions, in water, with an excess of oxygen, and in anaerobic conditions, with the presence of hazardous compounds or on any waste stream. The main requirements are an energy source and a carbon source. Because of the adaptability of microbes and other biological systems, these can be used to degrade or remediate environmental hazards. We can subdivide these microorganisms into the following groups:

Aerobic: In the presence of oxygen. Examples of aerobic bacteria recognized for their degrada-tive abilities are *Pseudomonas*, *Alcaligenes*, *Sphingomonas*, *Rhodococcus* and *Mycobacterium*. These microbes have often been reported to degrade pesticides and hydrocarbons, both alkanes and polyaroaromatic compounds.

Table 1: Some Contaminants Potentially Suitable for bioremediation

Class of contaminants	Specific examples	Aerobic	Anaerobic	More potential sources.
Chlorinated solvents	Trichloroethylene Perchloroethylene		+	Drycleaners Chemical manufacture.
Polychlorinated biphenyls	4-chlorobiphenyl 4,4-Dichlorobiphenyl		+	Electrical Manufacturing Power station Railway yards
Chlorinated phenol	Pentachlorophenol		+	Timber treatment Landfills
BTEX	Benzene Toluene Ethylbenzene Xylene	+	+	Oil production and storage Gas work sites Airports Paint manufacture Port facilities Railway yards Chemical manufacture.

Polyaromatic hydrocarbons	Napthalene Antracene Fluorene Pyrene Benzo pyrene	+		Oil production and storage Gas work sites Coke plants Engine works, Landfills, Tar production and storage, Boiler ash dump sites, Power station.
Pesticides	Atrazine Cararyl Carbofuran Coumphos Diazinon Glycophosphate Parathion, Propham 2,4-D	+	+	Agriculture Timber treatment plants Pesticide manufacture Recreational areas Landfills

Many of these bacteria use the contaminant as the sole source of carbon and energy.

Anaerobic: In the absence of oxygen. Anaerobic bacteria are not as frequently used as aerobic bacteria. There is an increasing interest in anaerobic bacteria used for bioremediation of polychlorinat-ed biphenyls (PCBs) in river sediments, dechlorination of the solvent trichloroethylene (TCE), and chloroform.

Ligninolytic fungi: Fungi such as the white rot fungus *Phanaerochaete chrysosporium* have the ability to degrade an extremely diverse range of persistent or toxic environmental pollutants. Common substrates used include straw, saw dust, or corn cobs.

Methylotrophs: Aerobic bacteria that grow utilizing methane for carbon and energy. The initial enzyme in the pathway for aerobic degradation, methane monooxygenase, has a broad substrate range and is active against a wide range of compounds, including the chlorinated aliphatics trichloroethylene and 1,2-dichloroethane.

An overview of the microbiological aspects of the application of microorganisms is given in [22]. For degradation it is necessary that bacteria and the contaminants be in contact. This is not easi-ly achieved, as neither the microbes nor contaminants are uniformly spread in the soil. Some bacteria are mobile and exhibit a chemotactic response, sensing the contaminant and moving toward it. Other microbes such as fungi grow in a filamentous form toward the contaminant. It is possible to enhance the mobilization of the contaminant utilizing some surfactants such as sodium dodecyl sulphate (SDS) [23].

Environmental factors

Nutrients:

Although the microorganisms are present in contaminated soil, they cannot necessarily be there in the numbers required for bioremediation of the site. Their growth and activity must be stimulated. Biostimulation usually involves the addition of nutrients and oxygen to help indigenous microorganisms. These nutrients are the basic building blocks of life and allow microbes to create the necessary enzymes to break down the contaminants. All of them will need nitrogen, phosphorous, and carbon (e.g., see Table 2).

Carbon is the most basic element of living forms and is needed in greater quantities than other elements. In addition to hydrogen, oxygen, and nitrogen it constitutes about 95% of the weight of cells.

Table 2: Composition of a microbial cell

Element	%	Element	%
Carbon	50	Sodium	1
Nitrogen	14	Calcium	0.5
Oxygen	20	Magnesium	0.5
Hydrogen	8	Chloride	0.5
Phosphorous	3	Iron	0.2
Sulphur	1	All others	0.3
Potassium	1		

Phosphorous and sulfur contribute with 70% of the remainders. The nutritional requirement of carbon to nitrogen ratio is 10:1, and carbon to phosphorous is 30:1.

Environmental requirements

Optimum environmental conditions for the degradation of contaminants are reported in Table 3.

Microbial growth and activity are readily affected by pH, temperature, and moisture. Although microorganisms have been also isolated in extreme conditions, most of them grow optimally over a narrow range, so that it is important to achieve optimal conditions.

If the soil has too much acid it is possible to rinse the pH by adding lime. Temperature affects bio-chemical reactions rates, and the rates of many of them double for each 10°C rise in temperature. Above a certain temperature, however, the cells die. Plastic covering can be used to enhance solar warming in late spring, summer, and autumn. Available water is essential for all the living organisms, and irrigation is needed to achieve the optimal moisture level.

The amount of available oxygen will determine whether the system is aerobic or anaerobic. Hydrocarbons are readily degraded under aerobic conditions, whereas chlorurate compounds are degraded only in anaerobic ones. To increase the oxygen amount in the soil it is possible to till or sparge air. In some cases, hydrogen peroxide or magnesium peroxide can be introduced in the environment.

Table 3: Environmental conditions affecting degradation

Parameters	Condition required for microbial activity	Optimum value for an oil degradation
Soil moisture	25-28% of water holding capacity	30-90%
Soil P^H	5.5-8.8	6.5-8.0%
Oxygen content	Aerobic , minimum air filled pore space of 10%	10-40%
Nutrient content	N and P for microbial growth	C:N:P=100:10:1
Temperature°C	15-45	20-30
Contaminants	Not too toxic	Hydrocarbon 5-10% of dry weight of soil
Heavy metals	Total content 2000 ppm	700 ppm
Type of soil	Low clay or silt content	

Soil structure controls the effective delivery of air, water, and nutrients. To improve soil structure, materials such as gypsum or organic matter can be applied. Low soil permeability can impede movement of water, nutrients, and oxygen, hence, soils with low permeability may not be appropriate for *in situ* clean-up techniques.

Types of Bioremediation

On the basis of removal and transport of wastes for treatment there are basically two methods

- In situ bioremediation
- Ex situ bioremediation.

In situ bioremediation: These techniques [24, 25] are generally the most desirable options due to lower cost and less disturbance since they provide the treatment in place avoiding excavation and transport of contaminants. *In situ* treatment is limited by the depth of the soil that can be effectively treated. In many soils effective oxy-gen diffusion for desirable rates of bioremediation extend to a range of only a few centimeters to about 30 cm into the soil, although depths of 60 cm and greater have been effectively treated in some cases. The most important land treatments are:

Bioventing is the most common *in situ* treatment and involves supplying air and nutrients through wells to contaminated soil to stimulate the indigenous bacteria. Bioventing employs low air flow rates and provides only the amount of oxygen necessary for the biodegradation while minimizing volatilization and release of contaminants to the atmosphere. It works for simple hydrocarbons and can be used where the contamination is deep under the surface.

In situ biodegradation involves supplying oxygen and nutrients by circulating aqueous solutions through contaminated soils to stimulate naturally occurring bacteria to degrade organic contaminants. It can be used for soil and groundwater. Generally, this technique includes conditions such as the infiltration of water-containing nutrients and oxygen or other electron acceptors for groundwater treatment.

Biosparging: Biosparging involves the injection of air under pressure below the water table to increase groundwater oxygen concentrations and enhance the rate of biological degradation of contaminants by naturally occurring bacteria. Biosparging increases the mixing in the saturated zone and there-by increases the contact between soil and groundwater. The ease and low cost of installing small-diameter air injection points allows considerable flexibility in the design and construction of the system.

***Bioaugmentation*:** Bioremediation frequently involves the addition of microorganisms indigenous or exogenous to the contaminated sites. Two factors limit the use of added microbial cultures in a land treatment unit: 1) nonindigenous cultures rarely compete well enough with an indigenous population to develop and sustain useful population levels and 2) most soils with long-term exposure to biodegradable waste have indigenous microorganisms that are effective degrades if the land treatment unit is well managed.

Ex situ bioremediation

These techniques involve the excavation or removal of contaminated soil from ground.

Landfarming is a simple technique in which contaminated soil is excavated and spread over a prepared bed and periodically tilled until pollutants are degraded. The goal is to stimulate indigenous biodegradative microorganisms and facilitate their aerobic degradation of contaminants. In general, the practice is limited to the treatment of superficial 10–35 cm of soil. Since landfarming has the potential to reduce monitoring and maintenance costs, as well as clean-up liabilities, it has received much attention as a disposal alternative.

Composting is a technique that involves combining contaminated soil with nonhazardous organic amendants such as manure or agricultural wastes. The presence of these organic materials supports the development of a rich microbial population and elevated temperature characteristic of composting.

Biopiles [26] are a hybrid of landfarming and composting. Essentially, engineered cells are constructed as aerated composted piles. Typically used for treatment of surface contamination with petroleum hydrocarbons they are a refined version of landfarming that tend to control physical losses of the contaminants by leaching and volatilization. Biopiles provide a favorable environment for indigenous aerobic and anaerobic microorganisms.

Bioreactors: Slurry reactors or aqueous reactors are used for *ex situ* treatment of contaminated soil and water pumped up from a contaminated plume. Bioremediation in reactors involves the processing of contaminated solid material (soil, sediment, sludge) or water through an engineered containment system. A slurry bioreactor may be defined as a containment vessel and apparatus used to create a three-phase (solid, liquid, and gas) mixing condition to increase the bioremediation rate of soil-bound and water-soluble pollutants as a water slurry of the contaminated soil and biomass (usually indigenous microorganisms) capable of degrading target contaminants. In general, the rate and extent of biodegradation are greater in a bioreactor system than *in situ* or in solid-phase systems because the contained environment is more manageable and hence more controllable and predictable. Despite the advantages of reactor systems, there are some disadvantages. The contaminated soil requires pre treatment (e.g., excavation) or alternatively the contaminant can be stripped from the soil via soil washing or physical extraction (e.g., vacuum extraction) before being placed in a bioreactor.

Advantages and Disadvantages

Advantages of bioremediation

- Bioremediation is a natural process and is therefore perceived by the public as an acceptable waste treatment process for contaminated material such as soil. Microbes able to degrade the contaminant increase in numbers when the contaminant is present, when the contaminant is degraded, the biodegradative population declines. The residues for the treatment are usually harmless products and include carbon dioxide, water, and cell biomass.

- Theoretically, bioremediation is useful for the complete destruction of a wide variety of contaminants. Many compounds that are legally considered to be hazardous can be transformed to harmless products. This eliminates the chance of future liability associated with treatment and disposal of contaminated material.
- Instead of transferring contaminants from one environmental medium to another, for example, from land to water or air, the complete destruction of target pollutants is possible.
- Bioremediation can often be carried out on site, often without causing a major disruption of nor-mal activities. This also eliminates the need to transport quantities of waste off site and the potential threats to human health and the environment that can arise during transportation.
- Bioremediation can prove less expensive than other technologies that are used for clean-up of hazardous waste.

Disadvantages of bioremediation

- Bioremediation is limited to those compounds that are biodegradable. Not all compounds are susceptible to rapid and complete degradation.
- There are some concerns that the products of biodegradation may be more persistent or toxic than the parent compound.
- Biological processes are often highly specific. Important site factors required for success include the presence of metabolically capable microbial populations, suitable environmental growth conditions, and appropriate levels of nutrients and contaminants.
- It is difficult to extrapolate from bench and pilot-scale studies to full-scale field operations.
- Research is needed to develop and engineer bioremediation technologies that are appropriate for sites with complex mixtures of contaminants that are not evenly dispersed in the environment. Contaminants may be present as solids, liquids, and gases.
- Bioremediation often takes longer than other treatment options, such as excavation and removal of soil or incineration.
- Regulatory uncertainty remains regarding acceptable performance criteria for bioremediation. There is no accepted definition of “clean”, evaluating performance of bioremediation is difficult, and there are no acceptable endpoints for bioremediation treatments.

Phytoremediation

Although the application of microbe biotechnology has been successful with petroleum-based constituents, microbial digestion has met limited success for widespread residual organic and metals pollutants. Vegetation- based remediation shows potential for accumulating, immobilizing, and transforming a low level of persistent contaminants. In natural ecosystems, plants act as filters and metabolize substances generated by nature. Phytoremediation is an emerging technology that uses plants to remove contaminants from soil and water [27-29] .The term “phytoremediation” is relatively new, coined in 1991. Its potential for encouraging the biodegradation of organic contaminants requires further research, although it may be a promising area for the future.

We can find five types of phytoremediation techniques, classified based on the contaminant fate: phytoextraction, phytotransformation, phytostabilization, phytodegradation, rhizofiltration, even if a combination of these can be found in nature.

Table 4: Summarizes the Advantages and Disadvantages of Bioremediation

Technology	Examples	Benefits	Limitations	Factors to consider
Insitu	Insitu Bioremediation Biosparging Bioeventing Bioaugmentation	Most cost efficient Noninvasive Relatively passive Natural attenuation Process Treats soil and water.	Environmental constraints Extended treatment time Monitoring difficulties	Biodegradable abilities of indigenous microorganisms Presence of metals and other inorganic Environmental parameters Biodegradability of pollutants Chemical solubility Geological factors Distribution of pollutants.
Ex situ	Landfarming Composting Biopiles	Cost efficient Low cost Can be done on site	Space requirements Extended treatment time Need to control abiotic loss Mass transfer problem Bioavailability limitation	Same as above
Bioreactors	Slurry reactors Aqueous reactors	Rapid degradation kinetic Optimized environmental parameter Enhances mass transfer Effective use of inoculants and surfactants.	Soil requires excavation Relatively high cost capital Relatively high operating cost.	Bioaugmentation Toxicity of amendments Toxic concentrations of contaminants.

Table 5: Overview of Phytoremediation Applications

Technique	Plant mechanism	Surface medium
Phytoextraction	Uptake and concentration of metal via direct uptake into the plant tissue with subsequent removal of plants	Soils
Phytotransformation	Plant uptake and degradation of organic compounds	Surface water , ground water
Phytostabilization	Root exudates cause metal to precipitate and become less available	Soils, ground water ,mine tailing
Phytodegradation	Enhances microbial degradation in rhizosphere	Soil, ground water within rthizosphere
Rhizofiltration	Uptake of metals into plant roots	Surface water and water pumped
Phytovolatiztion	Plants evaportranspirate selenium , mercury,and volatile hydrocarbons	Soils and ground water
Vegetative cap	Rain water is evaportranspirated by plants to prevent leaching contaminants from disposal sites	Soils

Phytoextraction or *phytoaccumulation* is the process used by the plants to accumulate contaminants into the roots and aboveground shoots or leaves. This technique saves tremendous remediation cost by accumulating low levels of contaminants from a widespread area. Unlike the degradation mechanisms, this process produces a mass of plants and contaminants (usually metals) that can be transported for disposal or recycling.

Phytotransformation or *phytodegradation* refers to the uptake of organic contaminants from soil, sediments, or water and, subsequently, their transformation to more stable, less toxic, or less mobile form. Metal chromium can be reduced from hexavalent to trivalent chromium, which is a less mobile and noncarcinogenic form.

Phytostabilization is a technique in which plants reduce the mobility and migration of contaminated soil. Leachable constituents are adsorbed and bound into the plant structure so that they form a stable mass of plant from which the contaminants will not reenter the environment.

Phytodegradation or *rhizodegradation* is the breakdown of contaminants through the activity existing in the rhizosphere. This activity is due to the presence of proteins and enzymes produced by the plants or by soil organisms such as bacteria, yeast, and fungi. Rhizodegradation is a symbiotic relationship that has evolved between plants and microbes. Plants provide nutrients necessary for the microbes to thrive, while microbes provide a healthier soil environment.

Rhizofiltration is a water remediation technique that involves the uptake of contaminants by plant roots. Rhizofiltration is used to reduce contamination in natural wetlands and estuary areas. In Table 5,we can see an overview of phytoremediation applications.

Phytoremediation is well suited for use at very large field sites where other methods of remediation are not cost effective or practicable, at sites with a low concentration of contaminants where only polish treatment is required over long periods of time, and in conjunction with other technologies where vegetation is used as a final cap and closure of the site. There are some limitations to the technology that it is necessary to consider carefully before it is selected for site remediation: long duration of time for remediation, potential contamination of the vegetation and food chain, and difficulty establishing and maintaining vegetation at some sites with high toxic levels.

Conclusion

Bioremediation provides a technique for cleaning up pollution by enhancing the natural biodegradation processes. So by developing an understanding of microbial communities and their response to the natural environment and pollutants, expanding the knowledge of the genetics of the microbes to increase capabilities to degrade pollutants, conducting field trials of new bioremediation techniques which are cost effective, and dedicating sites which are set aside for long term research purpose, these opportunities offer potential for significant advances. There is no doubt that bioremediation is in the process of paving a way to greener pastures. Regardless of which aspect of bioremediation that is used, this technology offers an efficient and cost effective way to treat contaminated ground water and soil. Its advantages generally outweigh the disadvantages, which is evident by the number of sites that choose to use this technology and its increasing popularity. Once again thanks to the bioremediation technology to clean up the polluted environment and therefore may be used as management tool.

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