



## Research Article

### Bioremediation of contaminated soil and water: An overview

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**Abstract:** 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 contamination of heavy metals to the water and soil are of great concern due to its potential impact on human and animal health. Bioremediation approach is currently applied to contain contaminants in soil, groundwater, surface water and sediments including air. The conventional techniques used for remediation have been to dig up contaminated soil and remove it to a land fill or to cap and contain the contaminated areas of a site. The methods have some drawbacks. Cheaper and effective technologies are needed to protect the precious natural resources and biological lives. The cultivation and harvest of animals to remediate nutrient and pathogenic microorganism pollution in aquatic systems is the most common form of zooremediation. Phytoremediation involves the use of certain plants to cleanup soil and

water contaminated with inorganic and/or organics. The phytoremediation technological development has led to plant gene manipulation and soil chelating treatments to facilitate plant uptake of heavy metals, which has improved its acceptance as a remediation tool. Rhizoremediation, which is the most evolved process of bioremediation, involves the removal of specific contaminants from contaminated sites by mutual interaction of plant roots and suitable microbial flora. Constructed wetlands are the result of human skill and technology integrating geology, hydrology and biology. Thus Bioremediation is emerging as an effective, environment friendly and innovative technology for treatment of a wide variety of contaminants in water and soil.

**Keywords:** bioremediation, zoo remediation, phytoremediation, Rhizoremediation, phycoremediation

## INTRODUCTION

Increased population, industrialization, urbanization and extraction of natural resources have resulted in large scale

environmental contamination and pollution. The problems associated with contaminated sites now assume increasing prominence in many countries. Inorganic pollutants which contaminate land and water bodies include heavy metals, metalloids, fluoride and cyanide etc. Normally heavy metals in the environment are in low concentrations but maybe elevated because of human activities, fossil fuel combustion, mining, smelting, sludge amendment to soil, fertilizer application and agrochemical application. The risk to human and environmental health is rising and there is evidence that this cocktail of pollutants is a contributor to the global epidemic of cancer, and other degenerative diseases.

All the current technologies that are available for treatment of waste have lots of limitations. Most of them are not cost effective and are inappropriate for the in situ treatment. Some of them are not effective in treating a complex array of different pollutants. The challenge is to develop innovative and cost-effective solutions to decontaminate polluted environments, to make them safe for human habitation and consumption, and to protect the functioning of the ecosystems which support life. However, advances in science and technology enabled us to apply the potential of biological diversity for pollution abatement which is termed as Bioremediation. Bioremediation has been successfully applied for cleanup of soil, surface water, groundwater, sediments and ecosystem restoration. This is emerging as an effective innovative technology for treatment of a wide variety of contaminants. Bioremediation is the process of using microorganisms to transform hazardous chemical compounds to non-hazardous end products. Almost all-organic compounds and some of the inorganic compounds can be degraded biologically if sufficient time

and proper physical and chemical conditions are provided.

Bioremediation is generally considered to include natural attenuation (little or no human action), bio-stimulation or bio-augmentation, the deliberate addition of natural or engineered micro-organisms to accelerate the desired catalytic capabilities. The present day bioremediation technologies are based on the processes and potentials of almost all types of life forms, viz., plants (phytoremediation), microorganisms (microbial remediation), plant root and microbe interaction (rhizoremediation), algae (phycoremediation) and animals (zooremediation). A variety of plants, natural, transgenic and/ or associated with rhizosphere micro-organisms are extraordinarily active in these biological interventions and in cleaning up pollutants by removing or immobilizing them. While diverse microbes are the most active agents, fungi and their strong oxidative enzymes are key players in degrading/ decontaminating recalcitrant polymers and xenobiotic chemicals as well. Thus bioremediation, is the use of biological interventions of biodiversity for mitigation (and wherever possible, complete elimination) of the noxious effects caused by environmental pollutants in a given site. The scope of environmental bioremediation extends to: Inorganic viz., Arsenic, Mercury, Chromium, Fluoride, Cyanide, abandoned mines, fly ash disposed sites, engineered phytotreatment technologies, biological permeable barriers; and Organics viz., petroleum hydrocarbons, pesticides and explosives. It contribute significantly to the fate of hazardous waste and can be used to remove these unwanted compounds from the biosphere (Ma *et al* 2011, Schroeder and Schwitzguebel 2004). Bioremediation is an invaluable tool box for wider application in the realm of environmental protection.

Bioremediation technologies have become attractive alternatives to conventional cleanup technologies due to relatively low capital costs and their inherently aesthetic nature.

**Objectives of bioremediation:** The main goals of bioremediation can be

- i) Enhancing the rate and extent of biodegradation of the pollutants in consideration.
- ii) Utilizing or developing microorganisms that is capable of surviving the toxic effects of the pollutants.
- iii) Utilizing the microorganisms in such a way that the products of the degradation process are not toxic.

**Bioremediation Strategies and Techniques: Bio-stimulation:** It involves the injection of the necessary nutrients to stimulate the growth of indigenous microorganisms. For example addition of nutrients, oxygen or other electron donors and acceptors. 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. Removal of inorganic materials by microorganisms may be achieved when the organic compounds are utilized as electron donors by the microorganism.

**Bio augmentation:** Bio augmentation is the introduction of microorganisms with specific catabolic abilities into the contaminated environment in order to supplement the indigenous population and to speed up or enable the degradation of pollutants (Louisa 2010). Two factors limit the use of added microbial cultures in a land treatment unit: 1) no indigenous 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.

**In situ techniques:** In situ bioremediation techniques are defined as those that are applied to soil and groundwater at the site/in the same place affected by pollution (U.S. EPA/625/K-96/001 and U.S. EPA/540/2-90/002). These techniques 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 oxygen diffusion for desirable rates of bioremediation extend to a range of only a few cm 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:

Bio venting is the most common in situ treatment and involves oxygen and nutrients by circulating aqueous solutions through contaminated soils to stimulate naturally occurring bacteria to degrade organic contaminants. Generally, this technique includes conditions such as the infiltration of water-containing nutrients and oxygen or other electron acceptors for groundwater treatment. It works for simple hydrocarbons and can be used where the contamination is deep under the surface.

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. It increases the mixing in the saturated zone and thereby increases the contact between soil and groundwater.

**Ex situ bioremediation:** Ex situ techniques are those that are applied to soil and groundwater at the site which has been removed from the site to a different place to

accelerate biocatalysts. These techniques involve the excavation or removal of contaminated soil and water from ground. It includes following techniques:

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 (Vidali 2001). Since land farming 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 amend ants 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 are a hybrid of land farming and composting (Fahnestock *et al* 1998). 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 land farming that tend to control physical losses of the contaminants by leaching and volatilization. Bio piles provide a favourable environment for indigenous aerobic and anaerobic microorganisms.

Bioreactors: 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. These 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. 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.

**Phytoremediation:** Phytoremediation is an emerging, cost-effective, simple and sustainable beneficiary technique technology that uses plants to remove contaminants from soil and water. This is done in-situ which is particularly useful as the site can be cleaned without the removal and replacement of containment material. Phytoremediation is currently being used to clean up contaminant metals, metalloids, petroleum hydrocarbons, explosive or toxic gases, chlorinated solvents, wood preservatives, explosives and pesticides and a range of industrial by-products. Soil with a high salt content has been cleaned up through the use of halophytes. These absorb the salt in a few years and then die allowing natural grasses to regrow. Commercially viable phytoremediation systems for clean-up of shallow aquifers and water-borne contaminant are now well in practice. Phytoremediation is most useful for sites where the contamination is spread over a large area where it would not be economically feasible to remove soil. Plants selected for bioremediation purpose are expected to possess one or more of the following properties: Taking up metals from soil particles and/or soil solution into their roots; Binding the metals into their root tissue (physically or chemically);

transporting the metals from roots into the growing shoots; preventing or inhibiting the metals from leaching out of the soil.

Such plants must not only accumulate metals but should also be fast growing in different conditions and lend themselves to easy harvesting. The binding of metals in plant tissue involves certain proteins known as metallothionins. Metal hyper accumulating species adopt different strategies to avoid metal toxicity, the most important being the vacuolar accumulation of the heavy metal.

Phytoremediation, involves number of processes including phytoextraction, phytotransformation, phytostabilization, phytovolatilization and rhizofiltration even if a combination of these can be found in nature (Prasad 2011).

Phytoextraction or phytoaccumulation is the process used by the plants to take up contaminants into the roots and translocate them to the aboveground shoots or leaves. For contaminants to be extracted by plants, the constituent must be dissolved in the soil water and come into contact with the plant roots. Once adsorbed, the contaminant may dissolve into the transpiration water or be actively taken up through plant transport mechanisms. 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. Research on the phytoextraction of pollutants has focused on a small group of plants known as hyper accumulators (plant species known to accumulate  $>100 \text{ mg kg}^{-1}$  Cd, Cr, Co or Pb; or  $>1000 \text{ mg kg}^{-1}$  Ni, Cu, Se, As or Al; or  $>10\ 000 \text{ mg kg}^{-1}$  Zn or Mn in their above ground biomass (Reeves and Baker 2000).

**Phytotransformation** 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 non-carcinogenic form.

**Phytostabilization** refers to the holding of contaminated soils and sediments in place by vegetation and to immobilizing toxic contaminants in soils. 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 re-enter in the environment.

**Phytodegradation** is the breakdown of contaminants through the activity existing in the rhizosphere. It refers to the uptake of contaminants with the subsequent breakdown, mineralization or metabolism by the plant itself through various internal enzymatic reactions and metabolic processes. Depending on factors such as the concentration and composition, plant species and soil conditions, contaminants may be able to pass through the rhizosphere only partially or negligibly impeded by phytosequestration and/or rhizodegradation.

**Phytovolatilization** is the volatilization of contaminants from the plant either from the leaf stomata or from plant stems (Anonymous 2009). Phytovolatilization occurs as growing trees and other plants take up water and the contaminants. Phytovolatilization is suitable for volatile compounds such as benzene, toluene, chlorinated alkanes and alkenes, as well as MTBE. **Phytovolatilization** is economically most efficient for such molecules since they are most frequently located on large surfaces, but in small concentrations. Some of these contaminants can pass through the plants to the leaves and volatilize into the

atmosphere at comparatively low concentrations.

**Rhizofiltration** can be defined as the use of plant roots to absorb, concentrate, and/or precipitate hazardous compounds, particularly heavy metals and radionuclides, from aqueous solutions. Hydroponically cultivated plants rapidly remove heavy metals from water and concentrate them in the root and shoots. Rhizofiltration is effective in cases where wetlands can be created and all of the contaminated water is allowed to come in contact with roots. Contaminants should be those that sorb strongly to roots, such as lead, chromium (III), uranium, and arsenic (V).

**Rhizoremediation:** It is the most evolved process of bioremediation, involves the removal of specific contaminants from contaminated sites by mutual interaction of plant roots and their root associated microbial communities (Barac *et al* 2009). Microflora associated with plants; endophytic bacteria, rhizosphere bacteria and mycorrhizae have the potential to degrade organic compounds in association with plants (Dowling and Doty 2009; Weyens *et al* 2009) and this process is termed rhizoremediation. Soil pollutants that are remediated by this method are generally organic compounds that cannot enter the plant because of their high hydrophobicity. Normally a symbiotic relationship develops between plant and soil microbes in the rhizosphere, where plants provide nutrients necessary for the microbes to flourish, while the microbes provide a healthier soil environment where plant roots can grow. Rhizoremediation is considered as the most potential approach for polycyclic aromatic hydrocarbons (PAHs) remediation in soil (Mohan *et al* 2006). Degradation is facilitated through rhizosphere effect where plants exude organic compounds through their roots and thereby increase the density

and activity of potential hydrocarbon degrading microorganisms in the zone, surrounding the roots (de Carcer *et al* 2007). Well established rhizoremediation processes are: Sequestration or immobilization or retention of toxicants within a confined area i.e. the soil at the site of their release or in contaminated soil placed in a landfill; removal of contaminants from the soil/waste water; destruction/degradation of organic pollutants by plant-microbial association. These three strategies either individually or in combination with each other have been routinely implemented to successfully treat contaminated soil. This type of phytoremediation is particularly successful for decomposition of organic compounds originating from petroleum and derivatives, as well as for compounds of BTEX complexes (benzene, toluene, ethylbenzene and xylene), pesticides etc. (Davidović *et al* 2014). Rhizospheric microbes can degrade the majority of environmental pollutants and degradation process stops when the microbe is deprived of food. Rhizoremediation appears a very promising technology for the removal of pesticides from polluted soil (Dubey and Fulekar 2013). The advantages of this method include in situ conditions for decomposition of polluting organic compounds, which contributes to considerable saving of financial resources on remediation of pollution, while the main disadvantage is the fact that this process takes a lot of time.

**Phycoremediation:** It may be defined in a broad sense as the use of macro algae or micro algae for the removal or biotransformation of pollutants, including nutrients and xenobiotics from wastewater and CO<sub>2</sub> from waste air (Olguín 2003). This field has evolved from the early work done by Oswald and Gotaas (1957) for the use of micro algae for tertiary treatment of

municipal wastewater to many other applications in which micro algae and macro algae are cultivated and utilized for specific bioremediation needs. Micro-algae are naturally occurring living organisms and therefore phycoremediation is a naturally occurring phenomenon. After phycoremediation is completed, the environment is virtually restored to its pristine condition. The unique feature about phycoremediation is that while it can be used in the treatment of wide variety of effluents, it can also be highly specific, for example, in the treatment of heavy metal-bearing effluents or dyeing effluents. Phycoremediation is case specific as the process can be operated batch-wise, semi-continuous or in continuous manner. It has been proved effective in treating array of effluents such as those of dye, food, chemical, pharmaceutical, dairy, oil drilling and pigment industries. There is no need to separate algae from the treated effluent as the process is an ecologically safe and natural process. Since micro algae are heavier than other microbes algal cells can be easily sedimented and harvested. In addition, micro-algae such as filamentous algae are available with high auto-flocculation capacity. It is highly compatible with existing operations such as physical, chemical and other biological methods. Phycoremediation technology is robust as it minimizes automation, maintenance and the need for skilled operators. Phycoremediation assures nil sludge generation and as a result there is no disruption of surrounding, non-contaminated areas. This technology is cost effective because it saves power and a lot of chemicals. The process generally is 70-90% less costly than other technologies as there is virtually little investment in "capital equipment". Furthermore, the only energy requirement for the process is solar energy, which is abundantly available in our

country. The crucial factor for social acceptance, particularly by environmentalists, is the conclusive impact of micro-algae on the biodiversity and this factor is best accepted in phycoremediation when compared with other methods.

Thus, phycoremediation comprises several applications: (a) nutrient removal from municipal wastewater and effluents rich in organic matter; (b) nutrient and xenobiotic compounds removal with the aid of algae-based biosorbents; (c) treatment of acidic and metal wastewaters. According to Becker (1983, 1994) utilizing planktonic algae with a high potential to absorb heavy metals for the removal of residual metals from waste waters including the separation of the metal-saturated algae from medium is an economic method resulting in high quality reusable effluent water and valuable biomass which could be used for different purposes (production of biogas, fertilizer, fodder etc.)

**Microbial bioremediation** is particularly useful for treatment of wastes and wastewater from municipal areas, food processing, agriculture sector, and more recently the hazardous wastes from various origins. Microbial bioremediation is a process by which microorganisms are stimulated to rapidly degrade hazardous organic contaminants to environmentally safe levels in soils, subsurface materials, water, sludge and residues. Microbes deal with poisonous chemicals by applying enzymes to convert one chemical into another form and taking energy or utilizable matter from this process. The chemical transformations generally involve breaking of large molecules into several small molecules in simpler form. In some cases the by-products of bacterial bioremediation are not only harmless but may prove useful. For example methane is derived by the bacterial degradation of sulphite liquor, a waste product in paper manufacturing.

We can subdivide these microorganisms into the following groups:

**Aerobic:** Examples of aerobic bacteria recognized for their degradative abilities are *Pseudomonas*, *Alcaligenes*, *Sphingomonas*, *Rhodococcus*, and *Mycobacterium*. These microbes have often been reported to degrade pesticides and hydrocarbons, both alkanes and polyaromatic compounds. Many of these bacteria use the contaminant as the sole source of carbon and energy.

**Anaerobic:** Anaerobic bacteria are not as frequently used as aerobic bacteria. There is an increasing interest in anaerobic bacteria used for bioremediation of polychlorinated 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. 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. Supported with sufficient nutrients and a terminal electron acceptor for metabolism, almost all the natural organics are biodegradable within a range of extent, but even simpler organic compounds fail to favor any microbial activity owing to unfavourable conditions like, extremes in temperature or pH, presence of toxicants or antimicrobial agents, lack of water, nutrient scarcity, absence of electron acceptor etc. It has been found that the process of bioremediation has been faster when the decontamination has been in situ rather than ex situ and it was also faster where there were pre-existing microbial populations and these were stimulated or enhanced.

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.

Thus, the ultimate goal of bioremediation is conversion of undesirable organic compounds into innocuous materials, usually carbon dioxide, water, inorganic salts and biomass. However, when biodegradation of compounds is incomplete, it may lead to accumulation of undesirable by products. The main deterrent to this process is the lack of favourable conditions. It can be stopped by various factors such as extremes of temperature, pH levels, presence of antimicrobial agents, lack of water, nutrients or electron receptors etc.

**Zooremediation:** When the decontamination of environment or waste treatment is performed through the activities of animals, the process is known as Zooremediation. Animals are rarely considered for bioremediation owing to ethical concerns or because many of the aquatic organisms currently cultured or harvested commercially are bound for human consumption. It is mentioned in literature that some animal species are very efficient remediators of heavy metals, microbiological pollution, hydrocarbon and organic pollutants, especially in aquatic environment. Recent examples include the use of shells (pearl shell) for the elimination of metals and organic substances from water ecosystems aiming at the removal of polychlorinated biphenyls (PCB). The cultivation and harvest of animals to remediate nutrient and pathogenic

microorganism pollution in aquatic systems is the most common form of zooremediation. Animals which are currently being used for this process are oysters, mussels, clams, fish, arthropods, polychaetes, sponges, earthworms and other filter feeders. Indeed, the literature reveals that oysters, mussels, clams, fish, polychaetes and sponges are suitable bioremediators and in aquatic ecosystems they hyperaccumulate, stabilize or degrade pollutant (Gifford *et al* 2005, Haamer 1996, Mackenzie *et al* 2004, Milanese *et al* 2003, Stabili *et al* 2006, Giangrande *et al* 2005). The practice has a long history in aquaculture, where polyculture can reduce nutrient and microorganism pollution from some monocultures. The most common group of animals used are bivalve molluscs, as demonstrated by the co-culture of salmon with mussels or oysters to reduce nutrient pollution from waste salmon feed.

It is probable that many animal taxa will possess attributes amenable to bioremediation. As with pearl oysters, sponges provide an ideal opportunity for profitable zooremediation. For certain sponge taxa, bath sponge material offers an alternative economic return for programs aimed at nutrient and microorganism pollution (the use of chemically exposed bath sponge material is unlikely to be accepted in the market). Sponges have been successfully deployed as zooremediators of microbial pollution. Edible molluscs are well established as zooremediators of nutrient pollution. However, as products of human consumption, great care needs to be maintained, either to depurate them of pollutants before sale or to culture the organisms in estuarine locations not impacted by other pollution sources such as microorganisms or metals.

Nonetheless, increasing mollusc culture in estuaries is an economically advantageous

method of nutrient stabilization and/or reduction in estuaries suffering from eutrophication. There is commercial potential however in the use of earthworms. Earthworms have ability to form Metal Rich Granules (MRGS). Earthworms store metals in subcellular compartments binding to phosphate, sulfur and metallothioneins, ultimately rendering metals toxicologically inactive. Therefore is an excellent animal model due to abundance in environment and ease in creating stable laboratory cultures.

The use of animals for bioremediation can be achieved in three ways: pollutants can be extracted from an area by harvesting wild populations; through the introduction, culture, and harvest of animals – a form of aquaculture; and supplementation or maintenance of wild animal populations, which might lead to stabilization or degradation of pollutants. The progress of research is also reflected in the introduction of new definitions used in the literature, such as zooextraction, zootransformation, zoostabilization, zoohyperaccumulation etc., which represent analogy to the terms of phyto-remediation (Gifford *et al* 2007).

**Zooextraction:** The harvest and treatment of pollutant-containing animal biomass. The focus rests on animal species known to accumulate pollutants of interest.

**Zoostabilization:** The use of animals to inhibit pollutant migration. This involves the maintenance or supplementation of wild animal populations without the harvesting of animal biomass.

**Zootransformation or Zoodegradation:** The use of animals to degrade organic pollutants to less toxic compounds. This involves the maintenance or supplementation of wild animal populations without the harvesting of animal biomass. The oyster has unique ability to remediate nitrate levels through chemical transformation.

**Animal metal-hyper accumulator:** Those animal species known to accumulate  $>100 \text{ mg kg}^{-1}$  Cd, Cr, Co or Pb; or  $>1000 \text{ mg kg}^{-1}$  Ni, Cu, Se, As or Al; or  $>10\,000 \text{ mg kg}^{-1}$  Zn or Mn. However, many questions need to be addressed before zooremediation can be optimized. The successful harvest of wild animal taxa for the zooextraction of pollutants requires a clear understanding of the population dynamics of candidate taxa, to ensure a sustainable harvest. The successful supplementation of wild animal populations with introduced species for zoostabilization requires an understanding of the risk of the candidate taxa perturbing local ecological communities. In addition, specific care must be exercised when contemplating the addition of exotic species, to avoid the risk of introducing invasive species. The use of animal taxa for zooremediation is likely to trigger substantial community and governmental interest. Several specialized animals have been identified that could function as a remediation model while, at the same time, produce a valuable economic product. Zooremediation has the potential to become an effective, environment friendly and inexpensive alternative to other remediation methods.

**Wetland Construction and Bioremediation:** Constructed wetlands are the result of human skill and technology integrating geology, hydrology and biology. Two kinds of wetlands are in the service of mankind: a) Natural wetlands - used for wastewater treatment for centuries; b) Constructed wetlands – effective in treating organic matter, nitrogen, phosphorus, decreasing the concentrations of trace metals and organic chemicals (Kadlec and Knight 1996).

Wetland plants have the ability to either take up oxygen from the air or use photosynthetic oxygen and translocate the oxygen to the

roots and into the rhizosphere. Thereby, they will increase the redox potential and thus also decrease the pH and increase the release of metals. Aquatic plants can tolerate a very low pH, which can be necessary when treating AMD. *Carexrostrata*, *Phragmitesaustralis*, *Typhaangustifolia*, *T. latifolia*, have been found growing under field conditions in pH as low as 2-4.4. The submerged aquatic macrophytes have very thin cuticles and therefore, readily take up metals from water through the entire surface. Aquatic macrophytes e.g. *Typhalatifolia*, *Eichhorniacrassipes*, *Ipomea sp.*, *Lemna minor*, *Polygonumsp.*, *Alternantheraphiloxeroides*, *Phragmitessp.* have paramount significance in bioremediation. These are being used in water quality assessment and also as fast track botanical cleanup crews (Prasad 2007, Prasad *et al* 2006b). They are important in nutrient cycling, controlling water quality, sediment stabilization and provision of habitat for a host of aquatic organisms.

Constructed wetlands are being designed for the treatment of municipal waste waters in developed nations. Due to the cost-effectiveness in the treatment of non-point source pollution, use of constructed wetlands is rapidly spreading in developed nations. However, in tropical nations due to water scarcity and high surface evapotranspiration, the constructed wetlands for treatment of waste waters is not gaining importance

**Biosurfactants and bioremediation:** Biosurfactants are surface active compounds released by microorganisms. They are amphiphilic biological compounds produced extracellular or as part of the cell membrane by a variety of yeast, bacteria and filamentous fungi (Mata-Sandoval *et al* 1999, 2000; Chen *et al* 2007) from various substances including sugars, oils and wastes. Oil spillage during offshore production

(drilling) and its transport from one location to another is seriously affecting aquatic life. Presently, biosurfactants are mainly used in studies on enhanced oil recovery and hydrocarbon bioremediation (Rahman *et al* 2004, 2006). Rhamnolipid biosurfactants produced by *Pseudomonas aeruginosa* DS10-129 showed significant applications in the bioremediation of hydrocarbons in gasoline spilled soil and petroleum oily sludge. Rhamnolipid biosurfactant enhanced the bioremediation process by releasing the weathered oil from the soil matrices and enhanced the bioavailability of hydrocarbons for microbial degradation. It is having potential applications in the remediation of hydrocarbon contaminated sites. Biosurfactants are also used in bioremediation of sites contaminated with toxic heavy metals like uranium, cadmium and lead (Miller 1995; Mulligan and Wang, 2006).

**Conclusion:** As a developing country, India has been paying more attention to economic growth and people's well-being. Due to rapid economic development, in recent times, environmental pollution and resources depletion problems have become major issues affecting the sustainable social and economic development. The balance between the economic growth and environmental/ecological protection has gradually become one of the key issues that should be taken into consideration by government officials, policy makers, company managers, scientists and engineers. Bioremediation is cost effective, solar driven, faster than natural attenuation, high public acceptance including enhancement of aesthetics and generates less secondary wastes with fewer air and water emissions. Bioremediation has emerged as an integrated 'toolbox' for environmental cleanup and ecosystem service provider. The

recent interdisciplinary approach of environmental problem solving through combination of biotechnology, microbiology, genetic engineering on the sphere of ecological practices has given rise to promising research and application of bioremediation tools. Typical organic contaminants such as petroleum hydrocarbons, gas condensates, crude oil, chlorinated compounds, pesticides, and explosive compounds and typical inorganic contaminants that can be addressed include salts (salinity), heavy metals, metalloids and radioactive materials can be remediated using bioremediation. Extensive databases are available covering a wide range of contaminants treated using bioremediation. Since bioremediation is based on natural attenuation the public considers it more acceptable than other technologies. As these technologies are quite safe compared to the application of chemical compounds, there is great potential for this technology. What must be remembered is that this, as with any new technology, must be implemented carefully and its projected environmental impact must be considered in great detail before it is used commercially and then it must be promoted and implemented in a responsible way. However, for optimizing the maximal benefit sustainability of such technologies, requires an effective policy directives supported by social perception and must necessarily incorporate the application of environmental impact assessments, intellectual property rights and cost-benefit analysis for commercial viability.

There are an increasing number of examples proving that bioremediation, but each of the mentioned procedures has certain advantages and limitations, and therefore a multidisciplinary approach is imposed as the most appropriate. Being relatively new, biotechnologies still have many open

questions, as well as great opportunities for further research. Since biotechnologies require various knowledge, there is a necessity of synergistic approach of different scientific disciplines directed to solving the same problem.

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