

AN OVERVIEW OF BIOREMEDIATION FOR POLLUTED ENVIRONMENT

Abstract

There has been a rise in environmental pollution across the world over the past decades because of various reasons. Bioremediation is the most popular and efficient cleaning mechanism that can get rid of toxic waste from the environment. Bioremediation is well regarded for eradication, degradation, detoxification, and immobilization of various hazardous materials and chemical wastes from the polluted environment with “all-inclusive action” of pathogens. The core concept of bioremediation is degradation and conversion of toxic pollutants into something less toxic. This process can be done in-situ and ex-situ as per various factors like nature of site, cost, pollutant concentration, and type. So, it is important to choose the right bioremediation technique. In addition, some of the mechanisms to develop bioremediation are bioaugmentation, bio-stimulation, biopiles, bioventing, and bio-attenuation. Bioremediation process can be conducted as per the environmental factors. It is the most economical, effective, and sustainable approach to control pollution. There are pros and cons of all bioremediation methods that will also be discussed in this chapter.

Keywords – bioremediation, polluted environment, environmental pollution, degradation, immobilization, detoxification

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I. INTRODUCTION

There is a direct relation between quality of life and overall quality of environment on Planet Earth. With the rise in global population, environmental pollution is also increasing from various sources [1]. Increase in pollution, declining natural resources, and other health-related problems are the outcomes of industrialization in every country [2]. Industrialization not just brings world-class innovations, but also improves social and economic aspects of societies [3]. Several health problems have been increased due to industrial revolution and amplified by various pollutants (Figure 1).

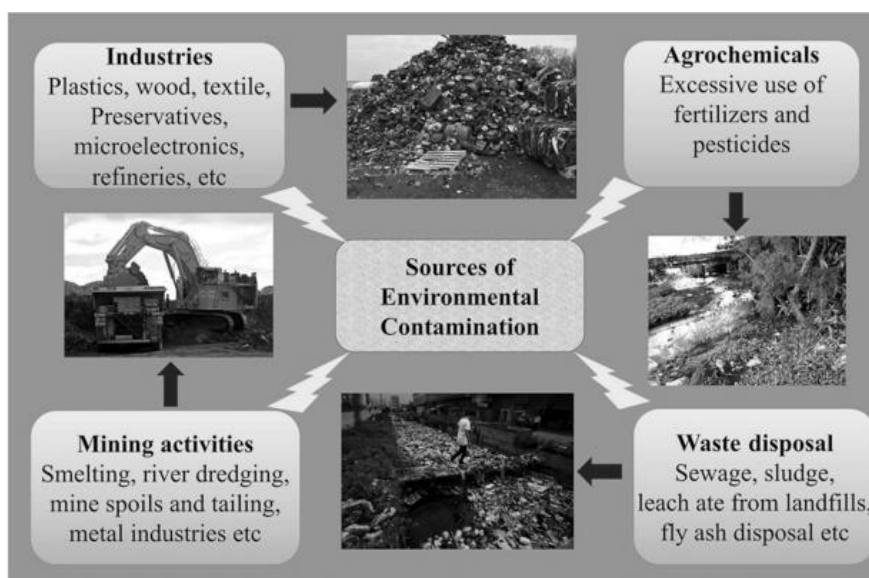


Figure 1: “Sources of Environmental Pollution [5]”

Environmental degradation and pollution are obnoxious partners of industrialization and technological advancements. These “revolutions have resulted in both accidental and intentional discharges of toxic chemicals, xenobiotics and gases to the open environment. It is time to design novel approaches to protect both environment and humans from extreme effects of pollution. There has been a rise in attention of practitioners and academicians on bioremediation of pollutants as people are looking for sustainable approaches in recent years [1,4]. Bioremediation is the solution to rising the problem of contaminants with the help of microbes like anaerobic, aerobic, fungi, and bacteria. This process is widely used in eradication, degradation, immobilization, or detoxification of various hazardous objects and chemical wastes from the environment with microorganisms. The rate of degradation is determined by biotic and abiotic conditions.

Population explosion, unplanned urbanization, unsafe agricultural practices, constant industrialization, deforestation, and unethical use of natural resources are some of the human activities responsible for environmental degradation. Nuclear wastes, pesticides, herbicides, chemical fertilizers, insecticides, heavy metals, and hydrocarbons are the pollutants responsible for public health and environmental concerns.

In bioremediation, these environmental pollutants are neutralized or removed by metabolic process using microscopic biological organisms like algae, fungi, and bacteria.

Microorganisms grow in different conditions in the biosphere like water, soil, animals, plants, deep sea, and ice.” They are the ideal environmental caretakers due to their hunger for different kinds of chemicals and their growth.

II. TYPES

There are different ways to use bioremediation. Figure 2 highlights some of the most common types of bioremediation process.

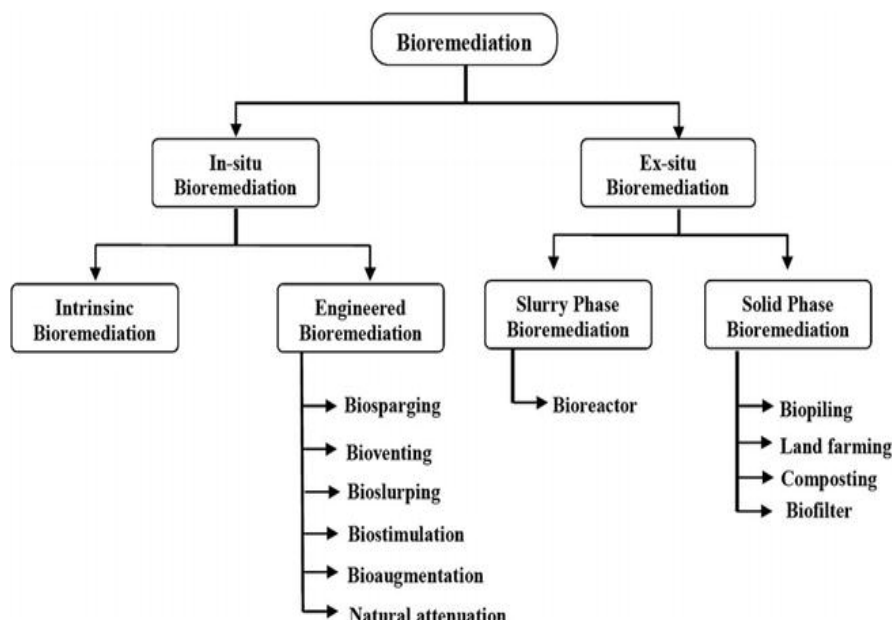


Figure 2: Types of bioremediations for cleaning environment [6]

1. Ex-situ Bioremediation: This process is ideal for different contaminants, easy to access with investigation data, and controls biodegradation better in bioreactor or solid-phase systems. However, it is not applicable to chlorinated hydrocarbons or heavy metal contamination and requires more processing in non-permeable soil.

- **Biopiling:** It consists of “irrigation, aeration, nutrients, leachate gathering, and treatment bed. It is an ex-situ bioremediation process known for its cost-effectiveness, which enables operative biodegradation like nutrient, pH, aeration, and temperature to be controlled well. Biopile is used to treat low molecular weight and volatile pollutants to remediate extremely chilled environments [7-9].
- **Windrows:** This bioremediation technique relies on regular rotation of piled contaminated soil to increase microbial degradation of transient and native hydrocarbonoclastic soil to improve bioremediation. It increases aeration by adding water, distributing nutrients, microbial degradation, and pollutants uniformly. It removes hydrocarbon more than biopiling [10].
- **Land Farming:** This process needs less equipment and low cost for operation, making it the easiest bioremediation technique. It is widely used in ex-situ bioremediation, but it is also used in in-situ techniques in some cases as per the site of treatment. Polluted and excavated soils are applied carefully on the fixed layer over the ground for aerobic biodegradation of pollutant [11].”

- **Bioreactor:** This vessel converts raw materials into specific products after some biological reactions. There are various bioreactor modes like fed-batch, batch, multistage, continuous, and sequencing batch. It is flexible enough for maximum biological degradation while controlling abiotic losses [12].
2. **In-situ Bioremediation:** It consists of treatment of polluted substances at target site. It doesn't disturb soil construction and doesn't need excavation. It is more cost-effective than ex-situ techniques. These techniques are well suited for treatment of sites polluted by heavy metals, chlorinated solvents, hydrocarbons, and dyes [13-15]. There are engineered and intrinsic bioremediations in this process. Intrinsic bioremediation consists of passive remediation of contaminated sites without human intervention. It stimulates naturally occurring or native microbial population. Both anaerobic and aerobic processes are involved to biodegrade polluting elements. On the other hand, in-situ bioremediation introduces some microorganism to the contamination site. These engineered microorganisms boost degradation by improving physicochemical to promote microorganism growth.
- **Bioventin:** It consists of controlled stimulus of airflow with the delivery of "oxygen to vadose zone to increase indigenous microbial activities for bioremediation. It has been popular among various in-situ techniques [16].
 - **Bioslurping:** It consists of soil-vapor extraction, vacuum pumping, and bioventing for groundwater and soil remediation with indirect delivery of oxygen and encouragement of biodegradation of contaminants [17].
 - **Biosparging:** It is much like bioventing in the air. It is injected in subsurface of the soil to improve microbial activities and boost pollutant removal. There are two important factors of its efficiency – biodegradability of pollutants and soil permeability.
 - **Phytoremediation:** It depollutes the contaminated soils. It is based on interactions with plants like chemical, biological, physical, biochemical, and microbiological in contaminated areas to eliminate toxic properties of pollutants. Chlorinated compounds and hydrocarbons are removed widely by rhizoremediation, degradation, volatilization, and stabilization [18].
 - **Permeable reactive barrier (PRB):** It is widely used as a physical approach to remediate toxic groundwater. Bioremediation and biotechnology can be used with bio-enhanced PRB, biological PRB, and passive bioreactive barrier. It can remediate chlorinated compounds and heavy metals in groundwater [19,20].

III. BIOREMEDIATION MECHANISM

Bioremediation applies microbes for degradation of pollution in the environment. It is environmentally sound and modern practice of using microbial processes to get rid of toxic pollutants. Microorganisms don't just regulate biogeochemical cycles, preserve the environment, keeping humans healthy, helping plants to grow, and controlling plant diseases, they also play their role in removing pollutants [21-23]. Microbial-controlled bioremediation is very important as it provides easier, cheaper, and more eco-friendly approach in comparison to non-biological measures where contaminants are just dug out or pumped up and transferred anywhere else [24].

However, bioremediation is still not a promising technique. It is because these methods are successful at one site but may not work in other areas. In addition, microbial processes which are proven successful to remediate pollutants in labs may not work well in fields. The actual reason is still not clear behind those failures. Hence, a lot of managers don't want to use bioremediation for cleaning up the environment. In addition, there is still lack of understanding of the mechanisms which manage the activity and growth of microorganisms in polluted sites, thereby reducing the use of bioremediation [24].

Nutritional flexibility, dynamic behaviour, and ability of adapting to unfavourable working conditions make microbes ideal life forms for bioremediation. This characteristic of microbes is beneficial and ideal for mankind, especially when eliminating pollutants and other hazardous chemicals. Microbes can degrade contaminants in the environment through different enzymatic processes to remove or reduce contaminants [25]. There are several microbes used to process bioremediation [26-28]. Microorganisms can restore the environment with different processes like volatilization, binding, oxidation, immobilization, or chemical transformation. Oxidation of toxic pollutants to safe products is one of the most common bioremediation processes (Figure 3).

The most popular acceptor of electrons for microbial respiration and aerobic degradation of different organic pollutants” like from “benzene to xenobiotics,” oxygen has been studied widely [29]. Though aerobic pollutants can be reduced by a huge phylogenetic diversity, *Pseudomonas* species are most widely tested organisms because they can degrade a lot of contaminants most intensively. These approaches should ideally be designed as per the understanding of specific microorganisms living in contaminated places like their metabolic processes and reaction of microorganisms to changing environment.

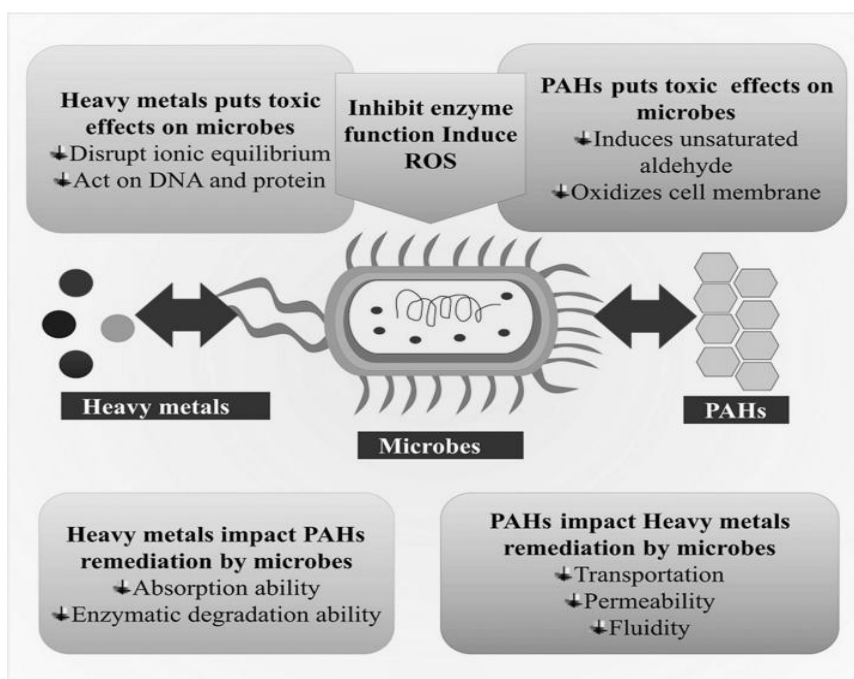


Figure 3: Bioremediation Mechanism [5]

IV. FACTORS

Bioremediation is the process of removing, degrading, immobilizing, changing, or detoxifying several pollutants and chemicals in the environment through “plants, fungi, algae, and bacterial activities. Enzymatic and metabolic paths of microorganisms promote the growth of biochemical reactions helping to degrade the pollutant. Microorganisms act on pollutants only while contacting with the compounds to generate nutrients and energy to amplify cells. There are various factors contributing to bioremediation effectiveness like concentration and chemical nature of pollutants, physicochemical properties of environment, as well as their accessibility to microorganisms [30]. Microbial population mainly degrades the pollutants, their accessibility to microbial population and factors like pH value, soil types, oxygen, temperature, and nutrients.

1. **Biological/biotic Factors:** Biological factors help in degrading organic elements using microorganisms with aggressive contacts, poor carbon sources, or bacteriophages and protozoa. The level of degradation of contaminants constantly relies on the amount of contaminant and catalyst in biochemical reaction. Some of the significant biological factors are mutation, enzyme activity, interaction, succession, predation, gene transfer, growth for biomass, composition, and population size [31,32].

2. **Environmental/Abiotic Factors:** Contact of contaminants in the environment with metabolic properties leads physicochemical activities of microorganisms which are targeted along the process. The proper interaction among pollutants and microbes relies on environmental factors. Microbial activity and growth rely on pH, temperature, soil structure, moisture, nutrients, solubility of water, oxygen content, site situations, redox potential, concentration, type, chemical structure, toxicity, solubility, and physicochemical pollutant bioavailability [33]. Pollutants are biodegradable under pH ranging from 6.5 to 8.5 for biodegradation in most terrestrial and aquatic environments. Moisture impacts contaminant metabolism” as it relies on the level and type of soluble elements and osmotic and pH pressure of aquatic and terrestrial systems [34].

Bioremediation must be capable to access current microorganisms and physicochemical properties in the environment to be successful (Table 1). It should consider the contaminant accessibility, microbial population that can degrade pollutants, and other factors.

Table 1: Important factors contributing to microbial bioremediation

Factors	Description	References
Moisture	In order to grow fully, microorganisms like ample amount of water. Biodegradation agents don't work properly in too wet soil.	[35]
Temperature	It is the most important factor affecting survival of microorganisms and composition of hydrocarbon. Oil degrades slowly in cold Arctic climates and microbes have added pressure to remove spilled oil. The channels of microbial transport are frozen by the sub-zero water temperature and they cannot	[36,37]

	perform microbial functions. Metabolic enzyme turnover is affected by temperature for degradation. In addition, degradation of each compound needs proper temperature. It affects physiological and microbial properties to slow down or speed up bioremediation. Higher temperatures lead to higher microbial activity. As the temperature reduces or decreases, it starts dropping all of a sudden and stops at the end.	
Nutrients	Microbial reproduction and growth are affected by nutrients along with effectiveness and frequency of biodegradation. Biodegradation can be improved by improving the “bacterial C:N:P (Carbon: Phosphorous: Nitrogen) ratio,” particularly with ample supply of N and P nutrients. These are few of the nutrients needed for survival by microorganisms. There is also limited degradation of hydrocarbon in limited concentrations. Metabolic activity and biodegradation of microorganisms can be improved by adding nutrients to cold areas. Availability of nutrients affect aquatic biodegradation. Nutrients have to thrive by microbes.	[38,39]
pH	The basicity, acidity, and alkalinity of a compound affect removal process and microbial metabolism. The pH level of the soil can predict microbial growth. Even minor changes in pH level have a vast impact on metabolic aspects.	[40]
Metal ions	Metals are vital for fungi and bacteria but cellular metabolism can be affected when there are excessive metals. Metal compounds affect degradation rates on both indirect and direct basis.	[41]
Site selection & characterization	Before bioremediation remedy is proposed, proper remedial test should be done to characterize the level of contamination. Site selection helps determine the vertical and horizontal level of contamination, defining sampling areas and parameters, and describing analysis and sampling approaches.	[42]
Microorganisms	Microorganisms can be affected by high levels of toxic compounds and slow process of decontamination. Toxicity level changes with exposure of microorganisms, concentration and toxicant.	[43]

V. APPLICATIONS

It is important to consider bioremediation as the right approach as it is applicable in all environmental matters –

- Solids like sediment, sludge, and soils
- Gases like carbon emissions from the industries
- Liquids like surface water, groundwater, and wastewater
- Sub-surface environment like vadose and saturated zones

The common approaches of bioremediation consist of (1) bio-simulation (environmental changes with aeration and nutrient application), (2) natural or intrinsic bioremediation, and (3) bio-augmentation (adding microbes). Biological community generally has innate microflora in the soil which is used for bioremediation. However, it is also possible to manipulate higher plants to improve the removal of toxicants like phytoremediation, particularly to remediate soils contaminated with metals. There have been different bioremediation techniques which have been proven effective to recover contaminated areas.

Microorganisms play a vital role in the process of bioremediation, especially their community structure, abundance, and diversity in contaminated environments. They provide insights if any bioremediation process can provide chance to other environmental factors which can affect any microbial activity. Modern molecular processes like “Omics” consist of proteomics, genomics, transcriptomics, and metabolomics, which have played a vital role in microbial functions, identification, catabolic and metabolic pathways. Low population, availability of nutrients, or lack of microbes with degradative functions as well as bioavailability of pollutant may delay the bioremediation process. Since microbial process matters on bioremediation, bioaugmentation and bio-stimulation methods boost microbial performance in polluted areas.

Microbial processes speed up with bio-stimulation while adding nutrients to the contaminated sample. Microorganisms are present naturally in various environmental conditions. It is evident that microbes that degrade pollutants are present naturally in polluted areas, their metabolic activities and growth relies on concentration and type of pollutant. Later, it is possible to use industrial and agricultural wastes like phosphorous, nitrogen, and potassium as a source of nutrition on most polluted areas. Microbial consortium is proven to efficiently degrade pollutants as compared to pure isolates [11].

Because of microbial changes of isolates, this activity creates potency from the source of isolation, composition of pollutant, adaptation process, and synergistic effects, which may help in rapid and complete degradation of pollutants with the blend of such isolates [44]. In addition, both bio-stimulation and bioaugmentation have effectively removed pollutants like “polyaromatic hydrocarbons (PAHs)” from sample which is highly polluted in comparison to non-amended control setup [45].

Even though effective approach has been identified in bio-augmentation, it has been popular to improve degradation of a lot of compounds. If there is no presence of proper biodegradation of microorganisms in soil or with the decline of microbial populations due to

toxicity of contaminant, it is possible to add specific microorganisms as “induced organisms” in order to improve existing populations and chance that “inoculated microorganisms” may not last long in the new environment. Hence, bioaugmentation process is very uncertain. In bioremediation, genetically tested or natural bacteria are used with different metabolic profiles to cure contaminated or sewage water or soil. Using agar, alginate, gelatin, agarose, polyurethane, and gellan gum as carriers can solve many problems in bioaugmentation [47].

Biosurfactants are chemical-based products which are biodegradable and eco-friendly. But they are not much scalable and have high construction cost on applicability to polluted area, making it uneconomical. The combination of agro-industrial wastes includes sources of nutrients to develop biosurfactant producers in the process of fermentation. Remediation efficiency can be improved by applying various bioremediation processes [47]. It is appropriate to improve bioremediation with proper use of “genetically engineered microorganisms (GEM).” It is because a “designer biocatalyst target pollutant” can be engineered with recalcitrant compounds with the combination of efficient and novel metabolic paths to extend the substrate of pathways and rising catabolic stability [48].

However, “multiplication of GEM” and “parallel gene transfer” are better approach for applying in the environment. Any GEM can escape the “bacterial containment system” to an environment to rebuild polluted environment. In addition, derivative path of GEMs with target contaminated site with biological method can improve bioremediation. The toxicity of pollutant can be declined to microorganisms by nanomaterials as they have higher surface area and reduced activation energy, with lower bioremediation cost and time [48].

VI. ADVANTAGES & DISADVANTAGES

All bioremediation techniques have different applications and their own pros and cons. Here are some of the benefits of bioremediation –

- Bioremediation takes a bit of time because it is the appropriate waste treatment of soil and other contaminated materials. Microbes can degrade the pollutant and reduce the “biodegradative populations. Usually, the treatment products are safe like water, cell biomass, and CO_2 .
- It can usually carry out on the area and needs much less effort, constantly without affecting usual microbial activities. It also removes the transport of waste off-site and common threats to the environment and human health.
- It is a cost-effective process as compared to other traditional approaches to remove toxic waste properly to treat oil polluted areas. It also helps in proper degradation of pollutants. It can transform a lot of hazardous and toxic compounds into products which are less harmful and can help dispose of toxic material.
- It is less labour intensive, simple, and cheap because it naturally plays a vital role in environment.
- It doesn't rely on any harmful chemicals. Fertilizers and other nutrients can make rapid and active microbial growth. Due to change in bioremediation, harmful chemicals are eliminated completely as they are transformed into safe gases and water.
- It is non-intrusive for proper use at site.
- It destroys the contaminants rather than just transferring to other environments.
- It is a sustainable alternative to remediate environment from vast contaminants.

Here are some of the cons of bioremediation –

- It is limited for biodegradable compounds. All the compounds are not disposed to complete and rapid degradation.
- There are new biodegradation products which are specially more toxic than previous compounds in environment.
- It requires boosting process from pilot-scale and bench to large-scale operations in the fields. There might be contaminants in liquids, solids and gases. It usually takes longer time as compared to other preferences for treatment like incineration, removal and excavation of soil.
- Biological processes are eco-friendly and highly specific with presence of microbial populations which are metabolically active, availability of contaminants and nutrients, and ideal conditions for environmental growth.
- More research is required to engineer and develop bioremediation techniques ideal for areas with complex blend of contaminants which are not spread equally in the environment.

Along with the above pros and cons, there are also some limitations of bioremediation as it is limited to biodegradable compounds. This approach is also subject to total and quick degradation. In addition, biodegradation materials may be more toxic and persistent than parent compound that is found in the environment”.

- **Scalability issues:** It is not easy to scale up the process of biodegradation from pilot-scale and batch processes to large field operations.
- **Limited:** The biological processes are mostly limited to particular areas. Sites must have microbial populations which are metabolically capable, proper levels of contaminants and nutrients, and ideal conditions for environmental growth to ensure success.
- **Research limitations:** For the development of modern bioremediation techniques which are ideal for areas with composite contaminants and their combinations which are not evenly distributed across the environment, more research is needed.
- **Time-consuming:** Bioremediation is also a time-consuming process in comparison to other options like extraction of soil and excavation from polluted site.
- **Regulatory issues:** Remediation cannot be considered completed fully as there is still lack of validation to prove cleanliness. Hence, there is no proper endpoint for such processes because of difficult evaluation of bioremediation performance.

VII. SUMMARY & CONCLUSION

Biodegradation is a very appealing and fruitful option to cleanse, remediate, recover, and manage polluted site using microbial activity. Degradation of unwanted waste can be increased with vital nutrients, low biodegradable, and uneasy abiotic conditions like moisture, aeration, temperature, and pH. As per various factors, bioremediation consists of site characteristics, cost, concentration, and type of pollutants. Site description is a prominent step for proper bioremediation which can create most promising and suitable in-situ and ex-situ bioremediation technique. Ex-situ bioremediation is supposed to be more expensive because of transportation and excavation from archeologic area. However, they can cure different types of toxins. On the other hand, in-situ biodegradation is cost-effective in excavation. But in-situ bioremediation approaches are not much effective because of on-site

cost of equipment installation to control subsurface of site. It is important to integrate geological properties of polluted areas having polluted depth and type, soil, performance of bioremediation, and human habitation area to determine the most operative and ideal bioremediation technique to treat contaminated site properly.

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