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BIOREMEDIATION AN ECO-FRIENDLY METHOD FOR ADMINISTRATION OF ENVIRONMENTAL CONTAMINANTS

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Abstract

Environmental pollution is a severe concern for the world . Chemical and physical approaches to pollution mitigation are insufficient so bioremediation has been used which is one among the most secure, cleanest, the most cost-effective, and the least harmful to the environment technologies that is made through the use of a variety of biological agents including microorganisms and\or plants (i.e. phytoremediation) to degrade, remove, stabilize and reduce different pollutants resulted from various industrial and anthropogenic activities due to a lack of knowledge about the manufacture, use and disposal of hazardous substances since they are extremely harmful and have a negative influence on human. To control increasing pollution it's necessary to keep looking for new biological forms because bioremediation is still considered an emerging technology . This review's objective is to provide a complete overview of the numerous types of bioremediation agents available, the different bioremediation techniques for example Bioaugmentation, Bioventing, Biosparging, Biocomposting, Biopiles and Bioreactors were applied in different part of the world to reduce the toxicity of toxic substance, advantage and disadvantage of bioremediation techniques as well as restrictions in treating contaminants in the natural environment.

Keywords: Bioremediation, Microorganisms, Phytoremediation, Hazardous Waste, Environmental Pollution.

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Introduction

Resources found in nature for example (forests, wind, wildlife, water, soil, air, land, plants, and animals) are abundant on the earth's surface . Since the population of humans and a high demand for expansion of industry for economic growth are expanding day after day, compressing is being placed on the depletion of our natural resources. Furthermore, since the industrial and technical development, environmental care and management have been lacking. As a result of rising global population, increased industrialization, an increase in human activities, and unregulated and unsustainable agricultural practices, hazardous contaminants as an example domestic, rubber, agriculture, plastic, industrial, and metallic waste has accumulated in the natural environment over the last few decades. The possible contaminants in this poisonous waste are heavy metals, pesticides, hydrocarbons (aliphatic and poly cyclic aromatic hydrocarbons (PAHs), petroleum oil, nitro-aromatic compounds, chlorinated hydrocarbons (perchloroethylene, poly chlorinated biphenyls (PCBs) and organ phosphorus compounds, phthalates and organic solvents (Gosavi *et al.,* 2004 ; Megharaj *et al.,* 2011) .

Given for growing number of polluted locations around the globe, a practical option to limiting the dispersion of contaminants while also lowering toxin levels is required. The bioremediation is referred to as a technique that uses the living organisms primarily plants, microorganisms and algae to degrade, remove, convert, mineralize, and detoxify toxic and dangerous compounds from the environment into harmless or in less harmful forms during the cleanup of contaminated regions to return them to their previous state, as shown in Figure. 1 (Azabuike *et al.,* 2016).

Microorganism-based bioremediation procedures using living microorganisms primarily bacteria and fungi to breakdown environmental contaminants offer a safe, low-risk, cost-effective, versatile, and environmentally friendly treatment option (Sharma *et al.,* 2021). A few species of fungus like as *Phanerochaete chrysosporium* it has been reported that successful in the treatment of a range of hazardous and persistent contaminants (Herakrushna and Kumar, 2012) . Biodegradation process is dependent on the favorable environmental circumstances which include the type of contaminant and it,s solubility, as well as bioavailability of pollutant to microbes .As a result, environmental conditions are manipulated or controlled to ensure adequate microbial development and as a result, quick and effective biodegradation (Tyagi and Kumar, 2021) . Basic research fields in bioremediation include co-metabolism, biotransformation kinetics, bio treatment, and biogeochemical modeling, as well as research areas for field applications (environmental attenuation, biogeochemical assessment, fate modeling, and co-metabolic technique) (Harekrushna and Kumar, 2012) .A main goal of this review is to concentrate on the involvement of diverse biological agents employed in bioremediation, as well as the numerous techniques of bioremediation such as ex-situ as well as in-situ remediation, it,s advantages, disadvantages and limitations. The review will be beneficial to humans in terms of better understanding bioremediation's feasibility and assisting in the selection of bioremediation products. The information gathered can be used to address contaminated environments on a national, regional and global scale.

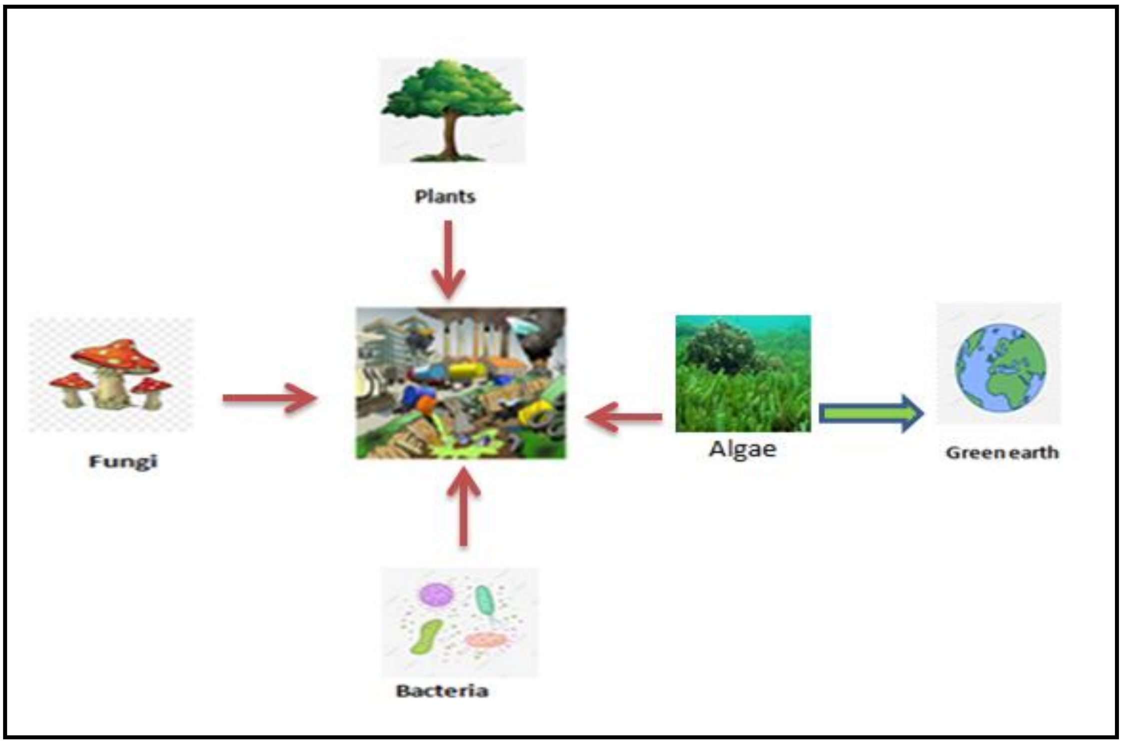

Figure 1: Explanation of the bioremediation process .

2. Bioremediation techniques

Bioremediation is classified as either ex-situ or in-situ depending on how it is applied

2.1 In-situ bioremediation

Its approach, which requires minimal excavation, can be utilized on dirty soil or water on the spot. It is categorized as either intrinsic in-situ bioremediation (with no enhancement) or enhanced in-situ bioremediation (Azubuike *et al.,* 2016). Although the in-situ method is more cost than ex situ bioremediation methods because there are no additional costs for excavation or transportation (only the costs of developing and installing the equipment to enhance microbial activity are necessary). This approach is used to effectively remediate dye, chlorinated solvent, heavy metal, and hydrocarbon-contaminated areas (Kim *et al.,* 2014; Tripathi *et al.,* 2021).

2.1.1 Intrinsic In-situ bioremediation

It is a type of bioremediation that occurs naturally in the environment. This bioremediation approach is also known as natural attenuation, and it is one of the most famous in situ bioremediation procedures. The unsupported and passive cleanup of contaminated places without human intervention is the goal of this strategy. For the treatment of both biodegradable and non-biodegradable contaminants, this technique uses both aerobic and anaerobic microbial activities. Despite the absence of any external factors, continuous monitoring is essential to maintain a long-term and successful process, which is why it is also called as natural attenuation (Azubuike *et al.,* 2016).

2.1.2 Enhanced In-situ bioremediation

This method of in-situ bioremediation entails excavating polluted locations or adding nutrients, air, and microbes to boost microbial growth and speed up the biodegradation process. Bio augmentation, bio stimulation, bio slurping, biosparging, and bioventing are some of the techniques used in enhanced in-situ bioremediation (Tiwari and Singh, 2014).

2.1.2.1 Bio augmentation

In this technique, to improve the degradation method a group of microbs that are native to the area or genetically modified microorganisms was injected to the contaminated site. It is primarily used to remediate aromatic and chlorinated hydrocarbon-contaminated soil and municipal wastewater (Sharma, 2012).

2.1.2.2 Bio stimulation

In this technique, The growth of native microbial populations in contaminated soil or groundwater is stimulated by providing essential nutrients for optimal pollution treatment. This is an effective approach for removing hydrocarbons and metal contamination from polluted locations (Kao *et al.,* 2008).

2.1.2.3 Bio venting

In this bioremediation process, nutrients and oxygen are given to the polluted soil in a controlled manner via wells to boost microbial activity in the breakdown process. This method involves adding very little oxygen to contaminated soil at low airflow rates, which is sufficient for successful microbial biodegradation while minimizing pollutant volatilization and emission to the environment (Atlas and philp, 2005). This approach can be utilized to successfully remove contaminants from deep within the earth's crust (Vadose zone). It was primarily utilized to degrade low molecular weight hydrocarbons, remains of fuel absorbed, light petroleum spilt in the soil, and volatile contaminants (Hohenar and Ponsin, 2014; Samuel and Ganiyu, 2015).

2.1.2.4 Bio slurping

It is a technology that combines a number of procedures, including vacuum enhanced pumping, bio venting, and extraction of vapor from the soil to remove contaminants from soil and groundwater while also accelerating microbial biodegradation. The limited soil permeability, which affects the rate of oxygen transfer, and so on reduces the activity of microbes, is a constraint of this approach. These methods are frequently employed to remove volatile and semi-volatile organic pollutants from soil and liquids (Vidali, 2001).

2.1.2.5 Biosparging

In contrast to the bio venting procedure, the soil subsurface receives air (i.e., saturated zone) in the biosparging process. As a result, volatile organic pollutants may migrate to the surface zone, where they can biodegrade, as well as boost the removal of pollutants from the polluted location through microbial activity stimulation. Two primary elements, namely permeability of the soil and pollutants biodegradability, aid this process (Kumar *et al.,* 2018). It has already been widely used to treat aquifers that have been contaminated by benzene, ethyl benzene, xylene and toluene are examples of hydrocarbons, and products of petroleum (Kao *et al.,* 2008).

2.2 Ex- situ bioremediation

This procedure used for cleaning up pollutants once they have been pumped or excavated to a suitable site (Ghangrekar *et al.,* 2020). This technique are additionally divided to other groups, such as land-farming, bio piling, bioreactor and bio filters on the basis of the pollutant kinds, pollution depth and severity, treatment costs, and geographical and geological characteristics of contaminated location (Atlas and Philip, 2005).

2.2.1 Bio piling

Biopiling also known as the heaping method, is a mix of composting and land farming techniques. It entails contaminated soil samples being tested in a lab to determine the soil sample's mechanical separation for homogenization, degradation potential, piling of excavated dirty soil, further nutrient supplementation, and forced aeration to improve microbial breakdown. In addition, powerful bacteria could be added to the bio pile for successful pollutant cleanup. This method of operation contains a bed for treatment as well as nutrients, and a system of aeration, a leachate collection system and a subterranean irrigation system (Azubake *et al.,* 2016).

The bio piling approach is frequently used to treat contamination of the soil by low molecular weight contaminants as well as PAHs, BTEX (benzene, toluene, ethyl benzene, xylene), and phenol are examples of petroleum hydrocarbons, but it might also be utilized to efficiently remediate a very polluted environment, as an example that found in cold climates (Dias *et al.,* 2015). Bio piling technology is becoming more popular for remediation owing to the ability to manage pH, nutrient and temperature conditions as well as its cost effectiveness (Whelan *et al.,* 2015).

2.2.2 Land-farming

In this method, Allowing aerobic biodegradation of a contaminants by auto-chthonous bacteria . soil that has been polluted is dug, disseminated, and tilled periodically over a set soil layer supported higher than the ground. During land-farming, tillage offers irrigation, aeration, and fertilizers to boost activity of microbes (Volpe *et al.,* 2012). Landfarming appears to be limited to (10-35cm) of surface soil treatment (Kumar *et al.,* 2018). Despite the fact that landfarming is classed as an ex- situ bioremediation technology, in some instances, it might be regarded as an in-situ bioremediation . This technology was mostly used to clean up contaminated sites with PCBs, aliphatic and PAHs (Silva Castro *et al.,* 2012). Because it requires less equipment, is less expensive and requires little maintenance, this technique is gaining popularity as a backup method of disposal (Wiliams, 2006).

2.2.3 Bioreactors

In this process, the pollutant is degraded under controlled conditions in a reactor or container. Solid waste (sludge, soil, and sediment) and water that have been contaminated are treated using slurry or aqueous reactors are examples of engineered containment systems (Vidali, 2001). Bioremediation with a focus on the bioreactors technology is the most useful due to factors like regulated bio-augmentation, supplementing nutrients, transfer of mass, bioavailability of pollutants and optimal reaction circumstances (Mohan *et al.,* 2004). This method is employed to treat water or soil that has been contaminated by organic pollutants for example BTEX . Because it has the potential to control, sustain, and alter the process parameters required for the biological mechanisms utilized in the bioremediation of pollutants, utilizing a bioreactor for bioremediation is significantly more efficient compared to other methods (Azubuike *et al.,* 2016).

2.2.4 Bio filters

The bio filter technique is mostly used to remove gaseous contaminants. The removal of gaseous contaminants is accomplished using columns embedded with microorganisms in this technology (Boopathy, 2000).

2.3 Phytoremediation

It is a new bioremediation approach that involves the application of plants and their roots to clean up contaminated soil and water. The vast majority of research studies have discovered that plants use passive uptake of contaminants to remove pollutants from a contaminated site, pollutant build-up in the shoot and xylem flow transfer from the root to the shoot (Miguel *et al.,* 2013). By functioning as a bio filter and removing the pollutant, bioremediation techniques based on vegetation have tremendous potential to degrade, immobilize, convert, and accumulate persistent pollutants (Meagher, 2000). phytoremediation thought to be a new and cost-effective method of bioremediation for hazardous contaminated areas .The phytoremediation method employs a number of approaches depending on the pollutant type (radionuclides, organic hydrocarbons, heavy metals, and chlorinated compounds), as well as the pollutant's destiny (degradation, transformation, accumulation, filtration, stabilization, volatilization, and the combination of these processes) (Kuiper *et al.,* 2004).

2.3.1 Phytoaccumulation or Rhizoaccumulation

It is also known as Phytoextraction, whereby plant roots directly absorb toxins from the soil and transport them to the tissues above the ground such as leaves and shoots, resulting in a large number of plants carry contaminants, which are then transferred for recycling and waste disposal (Wei and Zhou 2006; Meagher, 2000).

2.3.2 Phytodegradation or Rhizodegradation

It uses proteins and enzymes and generated by soil and plant microorganisms to degrade contaminants in the rhizosphere region . It is based on a symbiotic interaction among plant and microorganism, where nutrients are fed to microbes for biodegradation, and bacteria in the soil offer a favorable environment for decomposition method (Miguel *et al.,* 2013).

2.3.3 Phyto stabilization

In this method, plants restrict pollutant mobility in water and soil by generating a persistent plant mass with the pollution inside, minimizing the pollutant from moving to the ecosystem (Meagher, 2000).

2.3.4 Phyto transformation

This method included absorbing hazardous organic pollutants that contaminated sediment, soil, and water as well as converting them to harmless compounds (Kuiper *et al.,* 2004).

2.3.5 Rhizo filtration

Rhizo filtration is similar to phyto-extraction in that treats contaminated groundwater rather than contaminated soil. In this technique the contamination is initially uptaken by plant roots, and after that or deposited on the surface of the root or taken by the roots. for employ the plants in this method, it must first be acclimatized to a pollutant, then the acclimatized plants must be planted in a dirty groundwater, where the roots of the plants will ingest the pollutant in the contaminated water. After harvesting the polluted plant roots, they are carefully disposed of, and the contaminated site is treated repeatedly to ensure that all toxins are removed. Heavy metals are typically removed from groundwater contaminated with heavy metals, estuaries and natural wetlands using this phytoremediation approach (Miguel *et al.,* 2013).

3. Agents of Bioremediation

3.1 Microorganisms (Bacteria, Fungi, and Algae)

Microbes' ability to remove pollutants from polluted locations is one unique treatment technique (Sharma,2021). Microbes can be found in a variety of settings, including thermal springs, deserts, glaciers, salt lakes, and seas. For the elimination of a large number of variety of pollutants, microorganisms with degrading potential is capable of isolating itself from polluted environments like landfill, heavy metal polluted site, petroleum-contaminated site, pesticide-contaminated site from agricultural activities and wastewater treatment plants. In both aerobic and anaerobic settings, the toxic pollutants are utilized as a source of energy and carbon by microbes, hence can breakdown or alter the contaminant to harmless substances through metabolic activity (Tiwari and singh,2014). Bacterial species that are aerobic living including *Alcaligens*, *Sphingomonas*, *Mycobacterium*, and *Pseudomonas* are renowned for degrading of pesticides and hydrocarbons (alkanes and PAHs) . Furthermore, a few aerobic methylotrophs have been identified as degraders of chlorinated aliphatic (trichloroethylene) and dichloroethane.

Some bacterial species that are anaerobic living are renowned for degrading of chloroform, PCBs, and trichloro-ethylene (chlorinated solvents). Alongside bacteria, the use of fungal mycelium in mycoremediation to cleanse or clean up toxic waste from contaminated areas. Extracellular enzymes and acids secreted by fungal mycelia break degrade cellulose and lignin. The trick to mycoremediation is to figure out which fungal species to use to attack a given contaminant . Ligninolytic fungi like the white rot fungus *Phanaerochaete chrysosporium* and *Polyporus sp.* are attractive candidates for bioremediation, since it demonstrates the potential to decompose a wide range of persistent or harmful contaminant, including organochlorine pesticide, petroleum hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), explosives, and (PCBs) (Ayu *et al.,* 2011 ; Harekrushna and Kumar, 2012) .

Algae also plays a critical part in restoring the ecosystem to its pre-pollution state. The utilization of algae to eliminate contaminants from the environment or alter them to a harmless substance is referred to as phycoremediation. In a larger sense, phycoremediation is the use of microalgae or macroalgae to remove or biotransform pollutants such as xenobiotic and nutrients from wastewater and CO_2 from the air. Algae are highly adaptable organisms that may thrive in a variety of environments, growing autotrophically, heterotrophically, or mixotrophically. Algae play a critical role in regulating metal concentrations in oceans and lakes in natural settings. It has the potential to decompose or absorb hazardous heavy metals and organic pollutants from the environment, such as pesticides, polyphenols, hydrocarbons, and biphenyls, resulting in larger quantities within itself than in the water (Shamsuddoha *et al.,*2006). Mixotrophic algae that degrade pollutants are good agents for cleanup and carbon sequestration (Subashchandrabose *et al.,* 2013).

Mats of algae as an example *Aphanocapsa sp.*, *Synechococcus sp.*, *Plectonema terebrans* and *Oscillatoria salina* having been successfully employed in bioremediation of oil spills in a number of locations around the world (Rahman *et al.,*2011 ; Brahmbhatt *et al.,* 2012).

3.2 Plants

Phytoremediation is a quick method of cleaning contaminated environments. It has gained widespread acceptance and use as a reliable and environmentally beneficial green technology for the long-term elimination of pollutants (Chen *et al.,* 2009). The use of green plants and their biomass to breakdown or render harmless environmental pollutants is known as phytoremediation. In comparison to physical and chemical cleanup, phytoremediation has various advantages because it helps: (a) in order to preserve the rhizosphere microbial biomass at very high levels, (b) in conserving the natural features of soil, and (c) in obtaining energy primarily from the sun (Huang *et al.,*2004) . Despite these benefits, certain plants have a low tolerance for soil pollutants, limiting the degradation efficiency to a level that is insufficient for soil remediation. There are around four hundred plant species that operate as hyperaccumalator plants, divided into 45 different families. Rhizofiltration is the process of using plant roots and shoots to absorb and concentrate harmful chemicals, particularly heavy metals, from aqueous solutions. Heavy metals are rapidly removed from water by hydroponically farmed plants and concentrated in the roots and shoots. In wetlands, where contaminated water is permitted to come into touch with roots, the rhizofiltration process is effective. Soil bacteria that have demonstrated the ability to breakdown various organic contaminants employ exudates of plant root as a source of carbon and energy such as organic acid, sugars, and phenolics (Chaudhry *et al.,* 2005). Plant roots not only exude enzymes that degrade organic pollutants (lactase, dehalogenase, nitriles, and nitroreductase), but they also boost the degrading ability of microorganisms in the rhizosphere (Teng *et al.,*2010).

4. The advantages of Bioremediation

- It's a natural process that takes a little time and requires very little work, and it can often be done on-site without causing significant disturbance to usual operations. This also evade the require to transport huge amounts of waste off-site, as well as the health and environmental problems that might occur during transit (Abatenh *et al.,*2017).
- It's made use of in a cost-effective approach because uses fewer resources compared to others conventional methods (technologies) for hazardous contaminant cleanup. An important treatment strategy for oil-contaminated areas (Montagnolli *et al.,*2015).
- The phytoremediation process has several advantages, including improved soil fertility, precious metal recovery, metal deterioration control, as well as leaching prevention (Mench *et al.,* 2009).
- It doesn't include anything that could be dangerous compounds. Fertilizers and other nutrients are used to encourage microbial activity and growth. Typically seen in lawns and gardens. The toxic compounds are fully destroyed as a result of bioremediation, which transforms them into harmless gases and water (Shilpi, 2012).
- Remediation of natural ecosystems from a variety of contaminants that is both effective and more environmentally friendly. Also it has a higher level of public acceptance (Abha *et al.,* 2013; Ali *et al.,* 2013).
- Relatively simple to implement (Kumar *et al.,* 2011).

5. The disadvantages of Bioremediation

- It is only applicable to biodegradable chemicals. Not all chemicals are capable of complete and rapid breakdown (Abatenh *et al.,*2017).
- There are fears products of biodegradation will be more constant or hazardous with comparison to the parent molecule (Bhatnagar and Kumari , 2013).
- Because bioremediation is a process that requires a great deal of scientific knowledge, it ought to be customized to site-specific circumstances, which means a small-scale treatment feasibility study should be conducted beforehand using an approach to treat a contaminated site (Boopathy, 2000).
- It's tough to extrapolate full-scale field operations from bench and pilot-scale experiments.
- Bioremediation technologies that are suitable for environments with complex combinations of pollutants that are not evenly diffused in the environment require research to develop and engineer. contaminants can take the form of solids, liquids, or gases (Abatenh *et al.,*2017).

6. Restrictions of bioremediation

Because bioremediation is confined to biodegradable substances, not all compounds are capable of rapid and full breakdown. Some people worry that biodegradation products will last longer or be more dangerous than the parent molecule. Biological processes are highly particular in terms of culture conditions, making it challenging to generalize laboratory findings to the field at times. It also takes a lengthy time compared to conventional treatments like excavation and soil removal. There are some factors affecting the bioremediation process like depletion of favored substrates, nutrient deficiency, toxic effects and availability of pollutants, potential for oxidation or reduction, as well as microbial contact. Microbes (actions of enzymes, population diversity, and biomass concentration), substrate (molecular structure, physicochemical properties, and concentrations), and a variety of environmental conditions (pH, temperature, relative humidity, availability of electron acceptors, and carbon and energy sources) all influence the outcome of each degradation process (Bhatnagar and Kumari,2013) . These variables affect how long the microorganisms adapt to the substrate. The pollutant concentration and molecular structure have been found to have a significant impact on bioremediation feasibility. Whether the molecule is a primary, secondary, or co-metabolic substrate determines the kind of microbial transformation (Boopathy, 2000).

The procedure is restricted to surface plants and the surrounding region inhabited by roots, which is one of phycoremediation constraints. Furthermore, the device is ineffective in completely stopping the process of heavy metals leaching. The risk of pollutants bioaccumulating and bio-magnifying into plants, and ultimately via food chains to greater degrees, is always present. The major stumbling block is that few plants are large enough to be transferred from one location to another and used in the bioremediation process (Bhatnagar and Kumari,2013).

All pollutants are difficult to treat, accumulate, or degrade utilizing microorganisms in bioremediation, and the effects of microbes on leaching of metals in phytoremediation have received little study (Neagoe *et al.,*2009) . According to previous research, plant-assisted remediation does not necessarily speed up pollutant degradation and can possibly have a negative impact (Sung *et al.,*2004) . As a result, new strategies for example, genetic engineered microorganism or the combination of plant, fungus, as well as microbes are needed to provide exciting potential in the bioremediation process. For proper management of rising pollution and contamination, it is necessary to keep looking for new biological forms . As a result, Bioremediation is still recognized as a viable option as a rapidly evolving technology in order to deal with day-to-day environmental challenges that humans encounter in a given location.

7. Conclusion

The environment is rapidly polluted as a result of people's actions, industrial processes, and heavy metals. These contaminants are extremely hazardous. They can quickly deteriorate. Pollutants are detoxified using a variety of approaches. However, because they employ chemicals, they are exceedingly expensive and induce toxicity. Bioremediation, on the other hand, is regarded as a very safe and beneficial technology that poses no danger to the environment or to individuals. who live in the surrounding area, and it is an environmentally friendly remediation approach. that choose to employ this technology, as well as its growing popularity over time. Despite the availability of numerous agents of remediation, such as fungi, bacteria, algae, and plants, biological treatment alone is insufficient to remediate pollutants or contaminated locations when compared to other forms of physical and chemical method. It has been employed in a variety of places all throughout the world, with variable degrees of success. Generally, the advantages of bioremediation approaches exceed the disadvantages, as evidenced by the growing number of sites that use this technology, as well as with the passage of time, it has grown in popularity.

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