Asian Journal of Research in Social Sciences and Humanities
ISSN: 2249-7315 Vol. 11, Issue 11, November 2021 SJIF 2021 = 8.037
A peer reviewed journal

AN ANALYSIS OF ADVANTAGES, LIMITATIONS AND PROSPECTS OF BIOREMEDIATION TECHNIQUES

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DOI: 10.5958/2249-7315.2021.00205.7

ABSTRACT

Increased human activity on energy reserves, hazardous farming methods, and fast industrialization have all contributed to an increase in environmental contamination over the last several decades. Heavy metals, nuclear wastes, pesticides, greenhouse gases, and hydrocarbons are among the contaminants that cause environmental and public health problems owing to their toxicity. Because of its environmentally favourable characteristics, bioremediation of contaminated areas has proved to be efficient and dependable. Bioremediation may be done ex situ or in situ, depending on a variety of variables such as cost, site features, and the kind and quantity of contaminants. Ex situ methods seem to be more costly than in situ techniques in general, owing to the extra costs associated with excavation. However, when doing in situ bioremediation, the expense of on-site equipment installation and the difficulty to properly see and manage the subsurface of contaminated areas are significant issues. As a result, selecting the right bioremediation method to successfully decrease pollutant concentrations to safe levels is critical to a successful bioremediation project. Furthermore, bio stimulation and bio augmentation are two key methods to enhancing bioremediation, provided that environmental variables that influence bioremediation effectiveness are maintained at optimum levels. This study delves further into the two main bioremediation methods, their principles, benefits, drawbacks, and future possibilities.

KEYWORDS: *Biodegradation, Biological, Bioremediation, Pollution, Soil.*

1. INTRODUCTION

Recent advancements in bioremediation methods have been made in the last two decades, with the ultimate aim of successfully restoring contaminated ecosystems in an environmentally acceptable and cost-effective manner. Researchers have created and modelled many bioremediation methods; however, no one bioremediation strategy acts as a "silver bullet" for restoring contaminated ecosystems owing to the nature and/or kind of contaminant. Most of the difficulties connected with biodegradation and bioremediation of polluting chemicals may be solved by autochthonous (indigenous) microorganisms found in contaminated settings, provided the environmental circumstances are appropriate for their development and metabolism. Bioremediation has a number of benefits over chemical and physical remediation techniques, including environmental friendliness and economic savings. There have been many excellent definitions of bioremediation so far, with a focus on one of the processes (degradation). Nonetheless, the terms biodegradation and bioremediation are often used interchangeably; the former is a word that refers to a process that falls under the latter. Bioremediation is defined in this review as a method that uses biological processes to decrease (degrade, detoxify, mineralize, or convert) pollution concentrations to a safe level. The type of the pollutant, which may include agrochemicals, chlorinated compounds, dyes, greenhouse gases, heavy metals, hydrocarbons, nuclear waste, plastics, and sewage, determines the pollutant removal method[1]. According to the location of application, bioremediation methods may be classified as either ex situ or in situ. The kind of pollutant, the depth and degree of contamination, the type of environment, the location, the cost, and environmental regulations are all factors to consider when selecting a bioremediation method. Aside from selection criteria, performance criteria (oxygen and nutrient concentrations, temperature, pH, and other abiotic variables) that affect the effectiveness of bioremediation processes are also taken into account prior to the start of the project. Despite the fact that bioremediation methods are varied, the majority of research on the subject are focused on hydrocarbons due to the frequent contamination of soil and ground water by this specific contaminant. Furthermore, when remediation of sites contaminated with pollutants other than hydrocarbons is involved, it is conceivable that alternative remediation methods, which may be more cost-effective and efficient to use during cleanup, be explored. Furthermore, given the nature of the activities that cause crude oil pollution, contamination of the environment by contaminants other than hydrocarbons is likely to be readily avoided and managed. Furthermore, increasing pollution from this type of pollutant seems to be linked to our reliance on petroleum and other related goods as significant sources of energy. The goal of this study is to give a thorough understanding of the two main bioremediation methods in terms of application site, emphasizing their principles, benefits, limits, and potential solutions. Bioremediation's possibilities are also addressed[2].

1.1 Ex situ bioremediation techniques:

These methods include digging contaminants from contaminated areas and transferring them to a treatment facility elsewhere. The cost of treatment, the depth of pollution, the kind of pollutant, the degree of pollution, the geographical location, and the geology of the contaminated site are all factors to consider. Performance criteria have been established, which influence the choice of ex situ bioremediation methods[3].

1.1.1 Biopile:

Biopile-mediated bioremediation is stacking contaminated soil above ground, followed by nutrient enrichment and, in some cases, aeration, to improve bioremediation by essentially boosting microbial activity. Aeration, irrigation, nutrient and leachate collecting systems, and a treatment bed are the components of this method. The employment of this specific ex situ method is becoming more popular owing to its beneficial characteristics, which include cost efficiency and the ability to achieve efficient biodegradation under the condition that nutrition, temperature, and aeration are all properly regulated. The use of biopile on contaminated sites may assist reduce the volatilization of low molecular weight (LMW) contaminants, and it can also be utilized to successfully remediate polluted severe conditions, such as extremely cold areas[4].

1.1.2 Windrows:

Windrows depend on frequent rotation of piled contaminated soil to promote bioremediation by boosting the degradation activities of indigenous and/or transitory hydrocarbon clastic bacteria present in polluted soil. Periodic turning of contaminated soil, along with the injection of water, results in increased aeration, uniform distribution of pollutants, nutrients, and microbial degradative activities, accelerating bioremediation via absorption, biotransformation, and mineralization. Windrow treatment had a greater rate of hydrocarbon removal than bio pile treatment; however, the increased effectiveness of the windrow towards hydrocarbon removal was due to the soil type, which was found to be more friable. However, owing to the frequent turning involved with windrow treatment, it may not be the ideal choice for remediating toxic volatile-polluted soil. The application of windrow treatment has been linked to the production of CH_4 (greenhouse gas) due to the formation of an anaerobic zone inside piled contaminated soil, which happens when aeration is decreased[5].

1.1.3 Bioreactor:

As the name suggests, a bioreactor is a vessel in which raw materials are transformed into particular product(s) via a sequence of biological processes. Batch, fed-batch, sequencing batch, continuous, and multistage bioreactors all have various operating modes. The choice of operating mode is mostly influenced by the state of the economy and capital expenditure. A bioreactor's settings assist normal cell processes by simulating and preserving their natural environment to offer optimal growth circumstances. Contaminated samples may be fed into a bioreactor as dry matter or as a slurry; in any case, using a bioreactor to remediate polluted soil offers a number of benefits over conventional ex situ bioremediation methods.

One of the main benefits of bioreactor-based bioremediation is the excellent control of bioprocess parameters (temperature, pH, agitation and aeration rates, and substrate and inoculum concentrations). The capacity to regulate and modify process parameters in a bioreactor means that biological responses may be improved, resulting in a faster bioremediation process. Importantly, bioreactor-based bioremediation can successfully create regulated bio augmentation, nutrient addition, enhanced pollutant bioavailability, and mass transfer (contact between pollution and microorganisms), which are among the limiting elements of the bioremediation process[6].

Because different operating parameters can easily be controlled, bioreactor-based bioremediation has proven to be efficient. However, establishing the best operating condition by relating all parameters using the one-factor-at-a-time (OFAT) approach would likely necessitate numerous experiments, which is time-consuming. This problem may be solved by using design of experiment (DoE) tone, which gives information on the optimum range of parameters utilizing a collection of independent variables (controllable and uncontrolled factors) across a defined area (level). Regardless, when it comes to improving bioremediation procedures, understanding microbiological activities is critical. Furthermore, for a variety of reasons, bioreactor-based bioremediation is not a widely used full-scale technique.

To begin with, since bioreactors are an ex situ method, the amount of contaminated soil or other substances to be treated may be too big, necessitating additional personnel, money, and safety precautions to carry the pollutant to the treatment location, rendering this technology useless. Second, since a bioreactor has many bioprocess parameters or variables, any parameter that is not adequately regulated and/or maintained at an optimal level may become a limiting factor, reducing microbial activity and making the bioreactor-based bioremediation process less effective. Finally, contaminants are likely to react differently in various bioreactors, thus finding the most appropriate design is critical. Above all, the expense of a bioreactor appropriate for lab or pilot-scale bioremediation makes this a capital-intensive method[7].

1.1.4 Land farming:

Land farming is one of the most basic bioremediation methods due to its cheap cost and lack of equipment requirements. It is usually classified as ex situ bioremediation, although it may also be classified as in situ bioremediation in certain situations. This disagreement stems from the treatment location. The level of pollution has a big impact on whether land farming can be done ex situ or in situ. One thing is constant in land farming: contaminated soils are typically dug and/or tilled, although the kind of bioremediation seems to be determined by the treatment location. When contaminated soil is excavated and treated on-site, it is considered in situ; otherwise, it is considered ex situ since it is more similar to other ex situ bioremediation methods[8].

1.2 In situ bioremediation techniques:

These methods include treating contaminated substances at the contamination source. It does not require any excavation, thus there is little or no disruption to the soil structure. These methods should, in theory, be less costly than ex situ bioremediation techniques since no excavation is needed; nevertheless, the expense of designing and installing certain complex equipment to enhance microbial activity during bioremediation is a significant issue. Some in situ bioremediation methods may be improved, while others may continue without modification (intrinsic bioremediation or natural attenuation). Chlorinated solvents, dyes, heavy metals, and hydrocarbons have all been effectively treated using in situ bioremediation methods. Electron acceptor status, moisture content, nutrient availability, pH, and temperature are just a few of the essential environmental variables that must be met for in situ bioremediation to be effective. In contrast to ex situ bioremediation, soil porosity has a significant impact on the application of in situ bioremediation to any contaminated site[9].

1.3 Intrinsic bioremediation:

Natural attenuation, also known as intrinsic bioremediation, is an in situ bioremediation method that includes the passive remediation of contaminated areas without the use of any external force (human intervention). To biodegrade harmful chemicals, particularly those that are resistant, the method uses both microbial aerobic and anaerobic processes. Because there is no external force, the method is less costly than other in situ techniques. However, in order to ensure that bioremediation is continuous and sustainable, the process must be monitored, thus the phrase "monitored natural attenuation" (MNA). MNA is also often used to indicate a more comprehensive approach to intrinsic bioremediation[10].

Given that no external force is used to speed up the remediation process, one of the main drawbacks of intrinsic bioremediation is that it may take longer to reach the desired level of pollutant concentration. As a result, risk assessment must be conducted prior to the application of intrinsic bioremediation to guarantee that the remediation period is shorter than the time required for the pollutant to reach the exposure point in relation to the nearest human and animal populations. Furthermore, it has been observed that intrinsic bioremediation does not result in sufficient elimination of polyaromatic hydrocarbons (PAHs) and a decrease in contaminated soil eco-toxicity.

1.4 Bioremediation prospects:

Bioremediation methods are varied and have proved successful in recovering areas contaminated with many kinds of contaminants, as shown by the preceding. Microorganisms play a critical role in bioremediation; therefore, their diversity, abundance, and community structure in polluted environments provide insight into the fate of any bioremediation technique, assuming that other environmental factors that can obstruct microbial activities are kept within acceptable limits. Molecular approaches such as ‘Omics' (genomics, metabolomics, proteomics, and transcriptomics) have helped to improve our knowledge of microbial identity, functions, metabolic, and catabolic pathways, overcoming the limits of microbial culture-based methodologies. Nutrient restriction, a low population or lack of degradative microorganisms, and contaminant bioavailability are only a few of the main stumbling blocks to bioremediation effectiveness. Biostimulation and bioaugmentation are two main methods to speeding up microbial activity in contaminated areas, since bioremediation is dependent on microbial processes. The addition of nutrients or substrates to a contaminated sample in order to promote the activity of autochthonous microorganisms is known as biostimulation. Because microorganisms are ubiquitous, it is obvious that pollutant degraders are naturally present in polluted sites, and their numbers and metabolic activities may increase or decrease in response to pollutant concentration; thus, the use of agro-industrial wastes with appropriate nutrient composition, particularly nitrogen, phosphorus, and potassium, will aid in overcoming the problem of nutrient limitation in agriculture.

Simultaneous use of several bioremediation methods during cleanup can assist improve remediation effectiveness (by decreasing individual approach weaknesses) while also lowering costs. The use of integrated measures of bacterial dispersion network spatial configuration will be a useful indication of biodegradation performance. The regulated use of genetically modified microorganisms (GEM) to improve bioremediation effectiveness is a promising technique. This is due to the possibility of designing a designer biocatalyst (GEM) that can effectively degrade a target pollutant, including recalcitrant compounds, by incorporating new and efficient metabolic pathways, expanding the substrate range of existing pathways, and improving catabolic activity stability. Horizontal gene transfer and uncontrolled GEM proliferation in the environment, however, restrict the use of such a promising strategy. Despite this, bacterial confinement systems, in which any GEM escaping an environment is destroyed via induction of controlled suicide mechanisms, will aid public acceptance of the use of GEM to repair a contaminated environment.

2. DISCUSSION

Bioremediation is a technique of cleaning up polluted environments by using microorganisms' diverse metabolic capacities to convert pollutants to harmless products through mineralization, the production of carbon (IV) oxide and water, or the conversion of microbial biomass. It's important to note that the terms bioremediation and biodegradation should not be used interchangeably. Bioremediation as a technique may also include biodegradation as the most basic of the processes engaged or carried out in the bioremediation procedure. Only a few pollutants are biodegradable, and only a few bacteria are capable of degrading even a small portion of contaminants. As a result, it may be worthwhile to investigate microorganisms' biodegradation abilities. Various techniques and applications of bioremediation are covered in this review.

3. CONCLUSION

The most important stage in a successful bioremediation is site characterization, which aids in the selection of the most appropriate and viable bioremediation method (ex situ or in situ). Because of the extra expenses associated with excavation and shipping, ex situ bioremediation methods are often more costly. Nonetheless, they may be utilized in a regulated way to remediate a broad variety of contaminants. In situ bioremediation techniques, on the other hand, do not incur any additional costs due to excavation; however, the cost of on-site equipment installation, combined with the inability to effectively visualize and control the subsurface of a polluted site, may render some in situ bioremediation techniques ineffective. As a result, the cost of remediation does not seem to be the most important consideration when selecting a bioremediation method for a contaminated site. When determining the most suitable and efficient method to effectively treat polluted sites, geological characteristics of the polluted site(s), such as soil type, pollutant depth and type, site location relative to human habitation, and performance characteristics of each bioremediation technique, should be taken into account.

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