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Popular Article

Bioremediation: An Eco-Sustainable Tool for The Restoration of Polluted Environment

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Abstract

Environmental pollution has emerged as a burning environmental issue across the globe owing to increased human activities on energy reservoirs, unsafe agricultural practices, and rapid industrialization. These human-made activities generate organic and inorganic pollutants that remain persistent in the environment and pose a serious threat to living organisms. The commonly used physical-chemical methods for the removal of pollutants are not only expensive, but also their byproducts are hazardous to the environment, so they are not valued. A practical, eco-friendly and cost-effective solution for removing environmental contaminants is bioremediation.

Introduction

Numerous environmental contaminants significantly contribute to human and animal diseases, affecting climate change, public and individual health resulting in increased morbidity and mortality. The process of eliminating pollutants from the environment through physical, chemical, and biological methods is known as remediation. "Bioremediation is a technique that breaks down harmful materials into less toxic or nontoxic materials by using naturally occurring organisms" (Sharma, 2020). Through the use of bacteria, fungi, algae, plants, and enzymes working under controlled circumstances, bioremediation entails the degradation, removal, alteration, immobolization, or detoxification of different chemicals and physical wastes from the environment (Abatenh *et al.,* 2017). With advances in biotechnology, bioremediation has become one of the most rapidly developing fields of environmental restoration by reducing the concentration and toxicity of various chemical pollutants, such as petroleum hydrocarbons, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, phthalate esters, nitroaromatic compounds, industrial solvents, pesticides and heavy metals (Dua *et al.*, 2002).

Principles of bioremediation

A crucial component of bioremediation is biodegradation, which is the process of turning dangerous organic pollutants into naturally occurring or non-toxic materials like water, carbon dioxide, and inorganic compounds that are safe. Different groups of enzymes, including oxidoreductases, lyases, ligases, isomerases, transferases, and hydrolases, are found in microorganisms and are essential to biodegradation because they enable microbes to use contaminants as food for growth (Bala *et al.*, 2022). The microorganisms used for bioremediation at a contaminated site may be native to the area or they may be isolated and transported there from elsewhere (Tyagi and Kumar, 2021). By providing the right amount of nutrients and other substances necessary for their metabolism to break down and detoxify pollutants, microorganisms are stimulated to work. The effectiveness of bioremediation depends on the ability of the environment to support and accelerate microbial growth and activity. Utilizing genetically modified microorganisms that have improved degradative capacities across a broad spectrum of pollutants (Abatenh *et al.,* 2017).

Microorganisms and plants used in bioremediation

Aerobic bacteria: *Pseudomonas*, *Mycobacterium, Deinococcus radiodurans, Rhodococcus*, *Sphingomonas*, and *Alcaligene* etc., it has frequently been reported that these microbes break down hydrocarbons, polyaromatic compounds, alkanes, and pesticides.

Anaerobic bacteria: *Paracoccus denitrificans*, *Aeromonas* and etc., Anaerobic bacteria are becoming more and more popular when it comes to the bioremediation of river sediments containing polychlorinated biphenyls (PCBs), as well as the dechlorination of solvents like chloroform and trichloroethylene (TCE).

Methylotrophic bacteria: Aerobic bacteria that grow utilizing methane for carbon and energy. Examples include *Methylocella, methylocystis, methylococcus*. The enzyme methane

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monooxygenase, has a broad substrate range and is active against a wide range of compounds, including the chlorinated aliphatics trichloroethylene and 1,2-dichloroethane

Fungi: Fungi such as the *Phanaerochaete chrysosporium* (white rot fungus), *Pleurotus ostreatus* etc., have the ability to degrade an extremely diverse range of persistent or toxic environmental pollutants. (Vidali 2001).

Plants: *Helianthus annuus, Pteris vittate, Brassica juncea*, Ryegrass, Willow, *Arundo donax.* etc., phytoremediation is mostly used for heavy metals.

Techniques of bioremediation

Based on the site of application, bioremediation techniques are classified as *in-situ* and *ex-situ.*

(1). *In-situ* techniques

In-situ means that bioremediation occurs at the contaminated site, without the transfer of polluted materials. It contains the following techniques

i. Intrinsic bioremediation:

Intrinsic bioremediation depends only on the metabolism of native microorganisms to break down hazardous contaminants, no external force is used to accelerate biodegradation activity. So, it is also referred to as passive bioremediation or monitored natural attenuation. But in order for bioremediation to be ongoing and sustainable, monitoring must be ongoing. (Azubuike *et al.*, 2016).

ii. Enhanced bioremediation:

The physiochemical conditions are improved to promote the degradation of pollutants (Bala *et al.,* 2022). Biostimulation involves the addition of amendments like nutrients, air, oxidising & reducing agents to contaminated site to stimulate biodegradation by indigenous microbial population. Native or non-native microbes are added to a contaminated site to aid in biodegradation, in case of bioaugmentation (Rebello *et al.*, 2021). These are the basic techniques which are used in all other types.

Air, gas and nutrients are introduced into the unsaturated zone above the water table and saturated zone below the water table in bioventing and biosparging respectively to stimulate native microbes to degrade soil contaminants. Bioslurping combines vacuum enhanced pumping, soil vapour extraction and bioventing techniques to achieve soil and groundwater remediation, this can recover light non-aqueous phase liquids thus remediating capillary, unsaturated and saturated zones (Azubuike *et al.,* 2016). Permeable reactive barrier involves a membrane made up of iron, embedded with microbial mass is placed across the stream, mostly used to remediate ground water contaminated with

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heavy metals and chlorinated hydrocarbons. Phytoremediation is the use of plants (trees, shrubs, grasses and aquatic plants) and their associated microorganisms in order to remove, degrade or isolate toxic substances from the environment (Sales da Silva *et al.,* 2020). Phytoremediation techniques involve different strategies which include phytodegradation, phytostabilization, phytovolatilization, phytoextraction, phytofiltratiom and rhizodegradation depending on the nature and properties of the contaminant.

(2). *Ex-situ* techniques

In these methods, contaminants are removed from contaminated areas by excavation and then moved to a different location where they will be treated.

i. Solid phase:

Solid-phase bioremediation is an ex-situ technology in which the soil contaminated with organic waste like leaves, animal manures, agriculture wastes, domestic, industrial wastes and municipal wastes etc., is excavated and placed into piles. Microbes, air, nutrients are supplied through pipes that are distributed throughout the piles. Composting, biopiles, windrows, landfarming comes under solid-phase treatment processes and these are the most commonly followed techniques in rural as well as urban areas for waste management. Solid-phase system requires huge amount of space and cleanup require more time to complete as compared to slurry-phase processes (Kulshreshta *et al.*, 2014).

ii. Slurry phase:

In slurry-phase bioremediation, contaminated soil is combined with water, nutrient and oxygen to create the optimum environment for the microorganisms to degrade contaminants which are present in soil. Bioreactor, a vessel in which raw materials are converted to specific products following series of biological reactions. Constructed wetlands are the examples of slurry-phase treatment processes.

Factors affecting bioremediation

The bioremediation process is affected by several factors, which include scientific and non-scientific factors. Scientific factors constitute microbial factors like microbial biomass, its diversity, microbial metabolism, enzymatic activity; contaminant related factors like physicochemical characteristics, structure and concentration of contaminants; environmental parameters like pH, temperature, moisture present, carbon, energy sources, availability of electron acceptors. The interaction of the pollutant, nutrients, microbes and environment affects the bioavailability & biodegradability of pollutants, the physiological requirements for the degradation process, thus helping to assess the efficacy of the bioremediation process (Kumar *et al.*, 2018). Besides scientific factors, some non-technical factors that may affect the bioremediation process are regulatory, research, human resource, economic, and liability factors (Boopathy, 2000).

Conclusion:

Bioremediation has been used globally in different sites with varying degrees of success. It is the best suitable and non-replaceable technique for cleaning of our environment. Even it is a slow process, this technique is gaining importance as it is an eco-friendly and cost-effective substitute to mitigate the pollution load. Bioremediation techniques are diverse and all techniques have its own advantages and disadvantages, therefore the foremost step to a successful bioremediation is site characterization, which helps to establish the most suitable and feasible bioremediation technique. Recent advances in bioremediation involves use of omics approach and nanotechnology which helps in improving its efficiency. When used in conjunction with other physical and chemical methods, bioremediation can provide a comprehensive approach toward removing pollution from the environment. Since it appears to be a long-term solution, overall, more integrated and cross discipline efforts are required for the proper implementation of bioremediation techniques.

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