

CURRENT APPROACHES FOR BIOREMEDIATION OF POLLUTANTS TOWARDS SUSTAINABLE ENVIRONMENT

Abstract

Environmental pollution is a significant threat to the domain and human health. The pollutants, like polychlorinated biphenyls, agrochemicals, plastics and heavy metals are toxic and non-biodegradable present in the environment. Bioremediation removes such pollutants from polluted environments. Various aerobic and anaerobic microorganisms are used in bioremediation for eliminating degrading, detoxifying and immobilizing the pollutants from the environment. The main goal of bioremediation is to deteriorate the pollutants and convert it to innocuous forms. This can be achieved through in situ or ex situ bioremediation, based on the polluting agents, their concentration and the cost. This chapter highlights the most current advances in the techniques used for bioremediation process, the break down action of different pollutants, and subsequent strategies for bioremediation.

Keywords: Bioremediation, Ecosystems, Global Industrialization, Pollutants

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I. INTRODUCTION

Global industrialization has emerged as a major promoter for water, environment and soil pollution. The toxic heavy metal effluents eliminated from the steel and battery industries has worsened the water quality and is of major environmental concern. Waste products of polythene, petroleum, and trace metals are harmful to the environment. Pollutants such as heavy metals persisted in nature as ores and minerals. Their breakdown is hard in the environment, hence, remains toxic to great extent [1]. Such pollutants are mutagenic, their absorption and accumulation in the kidney, liver and brain leads to stunted growth, damage to the nervous system, cancer, and death [2]. The heavy metals inhibit the nutrients absorption, growth of plant, and other metabolic processes in the soil, thus, reducing the food quality and quantity. Such metal polluted soil may be alleviated through physical, chemical, and biological methods. Bioremediation is a practical way for eliminating the environmental pollutants. It is worthwhile, cost-effective [3] and has made significant strides in terms of cost, competency and social inclusion [4]. It is among the low-cost and environmentally advantageous innovative biotechnological approach. The waste treatment particularly depends on the bioremediation process. Bioremediation research centers on the bacterial processes, which have profusion of applications. In several applications, where bacteria are associated with bioremediation, *Archaea* plays a vital role. Microbes also biodegrade the acidic, hyperthermal, hypersaline, or basic industrial wastes [5-6]. In order to increase the efficacy and consequences of bioremediation, the researchers in current scenario have proposed the application of microorganisms more than one in numbers which allows for greater microbial diversity [7-8]. Several researchers have also used this technology for eliminating the pollutants both organic as well as inorganic types [9-10]. A study reports the use of *Aspergillus sydowii* for the management of organophosphate pesticides pollutants such as chlorpyrifos, profenofos and methyl parathion, and endophytic fungi for the management of chloramphenicol [11-12]. *Cymbella* sp. is also reported to alleviate the water contaminated with naproxen [13]. The perspective of bioremediation process uses the enzymes of microbes to breakdown the hydrocarbons into innocuous compounds. The genetically-modified microorganisms are widely used to remove the xenobiotic chemicals, petroleum, naphthalene, toluene, benzene [14]. The bioremediation is also influenced by some abiotic and biotic elements, such as temperature, aerobic or anaerobic conditions, and availability of nutrients, for better outcomes. The synthetic or natural environmental pollutants, such as toxins, heavy metals, and organic compounds, is added to the ecosystems basically through the anthropogenic activities and are a threat to the plants, animals as well as humans [15]. The chapter highlights the most current advances in the techniques used for bioremediation process for natural detoxification and the break down action of different pollutants.

II. APPLICATION OF MICROORGANISMS IN BIOREMEDIATION

The application of microorganisms such as, bacteria, yeast, fungi and algae, for elimination of the pollutants from the environment is called bioremediation [16]. Microbes have the tendency to grow in any waste stream with the lowest temperatures of -196 degrees Fahrenheit to highest temperature of 1200 degrees Fahrenheit. This versatility as well as their biological system makes them a perfect option for bioremediation [17]. The principal nutrient for microorganisms is carbon. The microbes adapted to different environmental conditions such as *Pseudomonas*, *Achromobacter*, *Xanthobacter*, *Alcaligenes*, *Nitrosomonas*

Arthrobacter, *Mycobacterium*, *Bacillus*, *Flavobacterium*, *Corynebacterium*, etc. [8] are used for bioremediation process.

- 1. Aerobic Microorganisms:** Several microorganisms such as *Sphingomonas*, *Bacillus*, *Rhodococcus*, *Flavobacterium*, *Pseudomonas*, *Nocardia* and *Mycobacterium* are capable to eliminate environmental pollutants under aerobic conditions. Such microorganisms either use the pollutant compounds as a source of energy or carbon or degrade and convert them to less harmful forms [18-19]. Oxygen remains the constraining factor for microbial growth and development under aerobic bioremediation conditions.
- 2. Anaerobic Microorganisms:** Several anaerobic bacteria such as *Aeromonas*, *Pseudomonas*, and sulfate-reducing bacteria, also bear the ability to degrade the toxic effluents such as chlorine compounds, polychlorinated biphenyls, the chlorinated solvents, trichlorethylene and chloroform, to the lesser toxic forms [20]. Garg and Tripathi [21] have reported the microbial approaches for discoloration and decontamination of azo dyes from textile pollutants. Azo dyes decomposes anaerobically through reduction reactions using electrons produced by the oxidation of the organic substrate(s). Due to such controlled dye decolorization events, microbe electrochemical properties would have a major impact on the effectiveness of color removal. Dyes were anaerobically decolorized for industrial activities to progressively acquire such time-variant decolorized-metabolites (DMs) [22].

III. FACTORS AFFECTING MICROBIAL BIOREMEDIATION

Bioremediation is the course of actions using microorganisms such as algae, bacteria, fungi, as well as plants to degrade, convert, eliminate, immobilize, or detoxify various pollutants in the environment. The degradation of the pollutants is accompanied by the increased rate of microbial enzymatic metabolic pathways [23-24]. With the aim to combat pollutants the microorganisms must associate with the compounds that are nutrients for them and gives them energy to multiply. Microorganism affecting the bioremediation process may be either single or consortium [25]. The microbial consortiums are multifunctional and exhibit resistance as well. The combined efforts of different microbial species in consortiums use all substrates in appropriate manner, and increase the efficiency of bioremediation as compared to single microorganism [26]. Carbon remains as the most essential nutrient for microorganisms that assist in situ bioremediation through elevation of their metabolic activity, thus, increasing the bioremediation process and degrading the pollutants. Therefore, the bioremediation process utilizes the organic carbon to greater extent than any other compounds. Many anaerobic microbes undergo fermentation and convert organic carbon to hydrogen gas [27]. Bioremediation process is influenced by different soil types. A study reports efficiency of bioremediation varies in clay soil and sandy soil [28]. For successful bioremediation process, it is important to access the existing microorganisms in the environment and its physicochemical characteristics as mentioned in Table 1.

Table 1: Critical Factors for Microbial Bioremediation

Factors	Remarks	References
Biological factors	The main biological factors include population size, composition and interaction (competition, predation, and succession). The degradation of organic compounds may be affected through interactions. For example, the competition among soil microbes for the carbon sources, or predation between bacteriophages and protozoa affect the degradation process. The rates are susceptible to pollutants and catalyst levels. Activated enzymes may increase or decrease the pollutant degradation.	[29-30]
Oxygen	The rate of biodegradation may be upgraded through anaerobic decomposition as most living organisms need oxygen to survive. Addition of oxygen also results to hydrocarbon metabolism in many cases.	[31]
Moisture content	Microorganisms need only limited amount of water to attain their growth. The biodegradation agents fail to function in extreme wet soil condition.	[32]
Nutrients	Nutrients effect the growth and multiplication of microbes, as well as their effectiveness and the rate of biodegradation. Biodegradation efficiency improves at optimum C:N:P ratio which are the only few of the nutrients required for microbes survival. Addition of nutrients may increase the microbial metabolic activity, hence, the biodegradation rate. Nutrients availability is essential requirement for the oil eating microbes to sustain their life and for aquatic biodegradation.	[33-34]
Temperature	Temperature influences the microbial survival, hydrocarbon composition, microbial physiological properties, the metabolic turnover of enzymes involved in degradation and thus increases or decreases the bioremediation rate. At higher temperature, microbial activity is high. In Arctic regions, natural oil degradation is slow, the sub-zero water freezes the microbial transport channels, rendering them unable to perform their metabolic functions.	[35-36]
pH	The acid, alkaline and basic nature of any compound has significant impact on the microbial metabolic activity and degradation. The growth of microorganism can be predicted by the pH of soil.	[37]
Site characterization and selection	Remedial investigation work such as determining the horizontal and vertical extent of contamination, defining parameters and sampling locations, and describing sampling and analysis methods must be characterized before proposing a bioremediation	[38]

	process.	
Metal ions	Metal ions exert a direct or indirect impact on the bioremediation process.	[39]
Microorganisms	The bioremediation process may slow down with the decrease in microbial population exposed to toxic compounds.	[40]

IV. PRINCIPLES OF BIOREMEDIATION

Bioremediation is termed as degradation of natural wastes under standard conditions. The process is associated with the degradation or detoxification of harmful substances by contributing nutrients and chemicals to the microorganisms involved. The metabolic process is enzyme controlled at each step [22, 41]. The enzymes involved belong to classes of lyases, transferases, oxidoreductases, and hydrolases and have the affinities for non-specific as well as specific substrate due to which the enzymes are capable to degrade a wide range of substrates. Therefore, for a promising bioremediation the pollutants must be acted upon by suitable enzymes. And this only works when the environmental parameters are favourable for the microbial growth. Bioremediation is also influenced by the living organisms and fertilizers. It is a primary element for bioremediation technology. It includes the conversion of harmful elements to useful organic compounds which are innocuous for plants, animals aquatic life and humans [42].

V. TYPES OF BIOREMEDIATIONS

Bioremediation can be used in a plethora of ways, and some of the diverse bioremediation techniques are as mentioned below:

- 1. Biopile:** Aeration and nutrient supplementation are adopted to increase the microbial metabolic activities in the piled-up polluted soil above ground. This increases the biodegradation rate and allows reduction in remediation time. The biopile's remediation process is assisted by the inclusion of bulking agents such as wood chips, sawdust and straw. Ex-situ bioremediation techniques like biosparging, land farming and bioventing furnishes the air supply to polluted piled soil in biopiles [43]. However, application of these techniques is challenging due to high cost. The biopile's remediation has significant effect of bio-available organic carbon (BOC). Biopile systems is also used to treat the diesel polluted soil of the sub-Antarctic region [44]. The rate of bioremediation is enhanced through acclimation, biological treatment, and mineralization of toxic aeration [44]. The efficacy of biopile remediation process is more than windrow treatment to remove hydrocarbons from the soil [45].
- 2. Land Farming:** Land farming is the simple ex situ bioremediation method due to its low operating costs and no requirement of any specialized equipment [46]. This method is commonly practiced in land farming to eliminate soil pollution. Land bioremediation of polluted soil using land farming bioremediation technology is a simple process which requires little capital, has little ecological footprint, and uses very little energy [47].

- 3. Bioreactor:** Bioreactors convert the raw materials into specific products undergoing a series of biological reactions,. The remediation samples are placed in a bioreactor. It provides the ideal condition that is required for the growth and increase of bioremediation [48]. A systematic bioremediation process in a bioreactors effectively regulates pH, aeration, agitation, temperature, substrate and inoculum concentration and decreases the time required for bioremediation [49]. Bioreactor designs maximizes the microbial degradation and minimizes the abiotic losses.
- 4. In Situ Bioremediation Techniques:** This method removes the polluted substances exactly where they are created without any digging or disturbance of the surrounding soil. The techniques are more cheap as compared to the ex situ bioremediation techniques. Bioventing, phytoremediation, and biosparging are examples of in situ bioremediation techniques that can be improved, while intrinsic bioremediation and natural attenuation are examples of in situ bioremediation techniques that cannot be improved [50]. The effectiveness of this technique has been reported for the treatment of chlorine, paints, toxic metals, and hydrocarbon-contaminated areas [51]. The in situ bioremediation method may be classified into two types: intrinsic and engineered.

 - Intrinsic in situ bioremediation utilizes the polluted areas in a non invasive manner. It is also termed as “Natural reduction”[52]. It is cheap. The goal of this procedure is to stimulate an already existing microbial population. This biodegradation method is based on aerobic and anaerobic processes in microorganisms. It can be executed applying aerobic treatment, anaerobic reductive dechlorination, amendment delivery, bioslurping and biosparging [53].
 - Engineered in-situ bioremediation includes the introduction of a specific microorganism into the area of contamination to clean it up. This technique employs the genetic engineered microorganisms in order to speed up the decomposition process. It is implemented by enhancing the physicochemical conditions which enhances the growth rate of microorganisms [54].
- 5. Bioventing:** Bioventing is a technique that utilizes controlled airflow to enhance the microbial activity for bioremediation process by remitting oxygen to the unsaturated zone. During the bioventing process the addition of nutrients and moisture enhances the bioremediation process transforming the pollutants into harmless compound. This technique stimulates the indigenous microflora and enhances the biodegradation ability of the various microbes and promotes decontamination of the heavy metal pollutants through precipitation [55].
- 6. Bioslurping:** Bioslurping uses oxygen, soil moisture and stimulation of contaminant biodegradation in conjunction with vacuum-assisted pumping, bioventing, and soil vapour extraction (SVE) [56] to recover unsaturated and saturated zones as well as light non-aqueous phase liquids (LNAPLs). This technology is used to improve the soils polluted with flammable and moderately-flammable organic substances. Liquid is drawn from the free product layer by means of a “slurp” that spreads into the layer. LNAPLs are lifted to the surface by the pumping machine, where they are separated from the surrounding air and water [57]. This method saves money on storage, disposal, and

treatment, however, it is not applied for low-permeable soils bioremediation process. This technique is applied at the depth of 25 feet and removes the floating water pollutants.

7. **Biosparging:** Biosparging involves introduction of air into the saturated zone of the soil's core to encourage microbiological activity and movement of flammable organic chemicals upward to an unsaturated zone. [58]. It removes pollutants from polluted sites. The success of biosparging is dependent on soil porosity and contaminant biodegradability. Biosparging is commonly practiced to remove diesel and kerosene from water supplies. The biodegradation processes, may be enhanced through oxygen supply into microorganisms.
8. **Phytoremediation:** This method uses plant interactions at the physical, chemical, biological, biochemical, and microbiological levels to detoxify the pollutant. The plant used must be disease free and insect resistant. The method employs various processes depending on the quantity and form of the pollutant [59]. Heavy metals are commonly eliminated through extraction, sequestration, and transformation. Tap root system or fibrous root system, penetration, toxicity levels, adaptability to the harsh environmental conditions of the contaminants, plant annual growth, supervision, and, notably, the time needed to reach standard of cleanliness are all important factors in plants that serve as phytoremediators. Phytoremediation removes pollutants from the shoots and roots. Phytoremediation is executed with the help of the majority of the plants present at a polluted site. About 300 plant species are recognized as ideal phytoremediators as they absorb Cu, Zn, and Ni. Bacterial aided phytoremediation is used for the treatment of contaminated water and waste water. The phytoremediation method of metal reduction in wastewater utilizing plants can be used by coalitions of growth promoting rhizobacteria, degrading bacteria, as well as endophytic bacteria [61].

VI. BIOREMEDIATION OF DIFFERENT POLLUTANTS

1. **Bioremediation for Organic Pollutants:** Organic compounds (OCs) have been widely used however, now they are a threat to life due to extensive use of these chemicals in the environment. Most OCs, such as polybrominated biphenyl ethers (PBEs), polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs), undergo microbial degradation in the environment through biodegradation process that uses microbes to break down organic compounds into less toxic or entirely non-toxic residues [62]. Microbes consume such OCs to obtain organic carbons and energy. Community microbe interactions bear chemical-degrading ability, and tolerance through exchange of genetic information among microbial species. Microbial degradation depends on the chromosomal genes, as well as the extracellular enzymatic activity (in the case of bacteria and fungal degradation process) attributed to the changes in environmental conditions that influences the microbial growth pattern [63]. Microbes thrive in an optimal environment as they are adapted to fluctuations in chemical gradient in their environment [64]. Recent developments in microbiological bioremediation are: Microbial consortia and microbial fuel cells (MFCs and bioreactors) which are used to degrade recalcitrant organic compounds. Toxic organics can be remedied more effectively using fungi rather than bacteria because bacteria cannot grow at high concentrations of toxic organics [65].

- 2. Bioremediation for Inorganic Pollutants:** Inorganic pollutants includes the toxic compounds resulted from mining, metallurgy, power plants and chemical manufacturing processes [66]. The disposal of toxic metals is challenging to the scientists due to health risks. Microbes change the oxidation states of the metals to stabilize them [67] and further metabolize and detoxify them in the cells. The metal ions and microbial cells first interact through physical adsorption, biosorption, and ion complexation [68]. Thereafter, the enzymes for oxidation, methylation, reduction, precipitation, and dealkylation are involved in the biochemical transformation of metal ions by microorganisms. Microbes can adapt to changing environmental conditions as demonstrated in the multidrug-resistant *Pseudomonas aeruginosa* T-3 isolate from tannery effluent which is adapted to heavy metals, such as iron, zinc, chrome, magnesium, mercury, and barium in textile waste [69]. Plasmid-encoded biochemical information and genetic engineering techniques were used to create recombinant *Escherichia coli* that expresses the metallothionein gene (*Neurospora crassa*) for Cd uptake, resulting in significantly faster Cd uptake than the donor microbe [70]. Introduction of a poly-histidyl peptide was into *Staphylococcus xylosus* and *Staphylococcus carnosus* encoded genes that allowed them to bind nickel [71].

VII. CHALLENGES AND CURRENT DEVELOPMENT IN BIOREMEDIATION

- 1. Bioinformatics Approaches in Bioremediation:** Bioremediation aims to utilize the data from different biological databases, such as databases of organic compounds, their chemical structure and composition, catalytic enzymes, RNA/protein expression, microbial degradation pathways, and comparative genomics in order to explain the basic mechanism of degradation that a particular organism carries out for a specific pollutant [72]. The different biological databases are interpreted by variety of bioinformatics tools that assists to develop an effective bioremediation process. Bioinformatics tools have been used to outline the microbes with bioremediation ability and map out their mineralization pathways and mechanisms [73]. The investigations are carried out using the technologies such as microarrays, two-dimensional polyacrylamide gel electrophoresis and mass spectrometry. Considerable improvement has been achieved in the structural characterization of microbial proteins that are able to degrade the pollutants. Nowadays, the information linked to the DNA, RNA, and proteins of the genome are stored, manipulated and retrieved using computers [72, 73]. Elaborative study of bioremediation process is possible through bioinformatics study exploring the Genomics, metabolomics, transcriptomics and proteomics of microbes.
 - **Genomics:** The process of biodegradation may be better explored through different genomic tools such as DNA hybridization, molecular connectivity, analysis of isotope distribution, PCR, metabolic engineering and DNA fingerprinting. DNA fingerprinting could be analysed through different PCR-based techniques such as, amplified ribosomal DNA restriction analysis (ARDRA), amplified fragment length polymorphisms (AFLP), randomly amplified polymorphic DNA analysis (RAPD), automated ribosomal intergenic spacer analysis (ARISA), single strand conformation polymorphism (SSCP), terminal-restriction fragment length polymorphism (T-RFLP) and length heterogeneity [139]. The soil microbes communities may be studied in

detail using techniques such as, genetic fingerprinting, RAPD, FISH, microradiography, quantitative PCR and stable isotope probing.

- **Transcriptomics and Metatranscriptomics:** Transcriptomics furnishes the global aspect of cellular phenotype, genome, interactome, and proteome throughout the human genome. In transcriptomics, DNA microarray assay are used to determine the mRNA expression levels [74]. Investigation of transcriptional mRNA profiles, also called as transcriptomics or metatranscriptomics, is however, a crucial process [75]. These are used by the researchers to analyse the gene expression [76].
 - **Proteomics and Metabolomics:** Metabolomics is associated with the total metabolites that is generated by an organism in a given period of time or environment, while proteomics centers around the total proteins expressed in a cell at a given location and time [77]. Proteomics analyzes the abundance of protein and variations in their composition, focussing the proteins related to the microbes. [78]. While genomics is the functional analysis of microbial communities. There are two fundamental means through which biological system could be analysed using metabolomics studies. Any prior knowledge related to the metabolic pathways of biological system is optional and not essential to conduct the study. Metabolic studies of microbes may be analysed by using the tools such as metabolite profiling, foot printing, and target analysis [79]. Both metabolomics and proteomics data are beneficial for cell-free bioremediation process.
2. **Nanotechnological Methods Used For Bioremediation:** Nanotechnology methods are nowadays used to remove many toxic substances because they bear unique abilities against various recalcitrant contaminants. Nanofiltration techniques is acceptable to the environment [80]. The nanotechnology method has given new perspective to the water treatment technology. For the treatment of wastewater as well as for water purification, nanotechnology and effective microbes (EM) technology are beneficially used. When the waste water is treated using EM technology with effective microbes, the water can be used for irrigation purpose [81]. The organic pollutants like polycyclic aromatic hydrocarbons (PAHs) with multiple benzene rings have been the source of innumerable and all-pervasive environmental issues. These pollutants are mutagenic and non-biodegradable [82] and may be biodegraded through engineered polymeric nanoparticles. PMUA nanoparticles are anticipated to maintain their properties in contiguity of diverse bacterial populations [83].
 3. **Genetic and Metabolic Engineering:** The editing in the sequences of gene through deletion, addition, or replacement of DNA pieces is called as gene editing. Such method uses the transcription activators such as TALENs, ZFNs, and CRISPRs for editing gene sequence. New perspective focuses on the use of composite endonuclease (including TALENs and ZFN nucleases) to unravel the molecular problems [84-85]. Two of the CRISPR-Cas system's unique properties are sequence similarity complementarity and simultaneous gene editing [86-87]. Such gene editing tools with knock-in and knock-out effects are examined and applied in bioremediation investigations [88]. The gene editing tool may be used to enhance and upgrade the bioremediation process through improved metabolic engineered pathways. The pollutant-tolerant bacteria which bear the ability to

store toxic, non-biodegradable compounds and have high survival rate under harsh conditions are preferred for genetic manipulation. Reports suggest that the activity and stability of enzymes significantly increases with the immobilization of enzymes. The microbial enzymatic bioremediation is a simple, fast and environmentally-friendly process to remove and degrade the persistent toxic compounds [75].

- 4. Designing the Synthetic Microbial Communities:** Advancements in the synthetic biology have substantial effects on the environmental issues and are the matter of concern in recent years. The genetically modified organisms are now efficient and effectively remove the toxic pollutants, xenobiotics and pesticides from the environment. The natural communities of microbes communities need to be implicated to design a synthetic one [89]. The created synthetic community of microbes may be used to develop an artificial functional species specific microbiome. The structural and functional features of such created synthetic communities must be analysed and researched through model systems. These communities were created by the co-culture technique in which two distinct microorganisms were cultured together under defined conditions, based on their functions and interactions. The structure and dynamics of synthetic communities depend on these variables and bacterial processes and behaviours. Social interactions between two populations of microbes may exist as mutualism, competition, and cooperation among which cooperation is the fundamental aspect in structure and operation of the community. The created synthetic communities exerts an influence on the cooperation in community dynamics [90] and it was established that cooperation between two microbial strains could be engineered through modification in the environmental conditions, such as deleting genes. Furthermore, these engineered microbial species of the synthetic community were also detected for more patterns of interaction. Such types of engineered interaction are often used for bioremediation approach [91]. Synthetic biology encourages the prevalence of microorganisms in large populations.

VIII. CONCLUSIONS WITH FUTURE PERSPECTIVES

The eminence of Omics in the field of microbial remediation of the food industry, pulp and paper industry, dairy industry, textile industry, wood industry, fisheries, water and soil treatment industry, solid waste remediation, heavy metal pollution remediation, and hydrocarbon remediation is a new strategy extensively studied by researchers. Degradative pathways need to be elaborated. Standard protocols for data assemblage, repositioning, exploration, and transmission, need to be developed. The data of omics copled with the genetically-engineered tools may give a general view of the microbial bioremediation. Involvement of phytoremediation to reduce environmental pollution can be extensified. The air pollutants, groundwater pollutants, and toxic waste product of semiconductor manufacturings, are hazardazous for environment. The pharmaceutical pollutants are environmentally persistent substances and are a threat to the environment.. Several urban and rural sources of groundwater retain the trace quantity of pharmaceutical ingredients, such as anti-epileptics, birth control pills, antidepressant medications and pain relievers. Certain specific pollutants may be degraded through the enzymatic metabolic processes, genes as well as operons discovered in the genetically-engineered plants. In bioremediation, genomics, metabolomics, and proteomics may be used to explore the possible solution to specific pollutant. Further, bioremediation research may be extended for analysing and determining the sequences of genes and protein sequences that are efficient for eliminating the pollutants.

GMOs are highly efficient for extensive removal of waste effluents and clean up the polluted land. The concurrence of GMOs with other physical and chemical methods may bring advancement in the complete elimination of pollutants from the environment. The problem needs an extensive, elaborative and everlasting solution, thus, an additional research is essentially required in this area at present time.

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