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A Review: Different Sources of Soil Pollutant and Bioremediations with Organisms

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Abstract

Bioremediation is the term used to describe biological strategies applicable to repair of damaged environment using biological factors. Microorganisms can release enzymes in soil and the enzymes have the ability to catalyze the oxidation of a variety of different hydrocarbons indicated by their broad substrate specificities. The enzyme activity of soil is the sum of the activity of al1 accumulated enzymes. The native enzyme activity is the result of many processes which lead to partial incorporation of locally produced enzymes into the soil environment. In other words these enzymes are immobilized at the surface of the soil particles. In the last few decades, highly toxic organic compounds have been synthesized and released into the environment for direct or indirect application over a long period of time. Petroleum hydrocarbons, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), pesticides and dyes, Radionuclides and Heavy metals are some of these types of compounds. Nowadays, several bioremediation techniques have been applied for contaminated soil treatment. For instance, these remediation techniques can be carried out either on the site or out of it. According to EP on the basis of removal and transportation of wastes for treatment there are basically two methods. These are in-situ bioremediation (bioventing, bio augmentation and bio stimulation) and ex-situ bioremediation (bioslurry system bioreactor), land farming, biopiles and composting). There is different organisms participated on bioremediation proses. This are different plants species, (*Ambrosia artemisifolia*, *Apocynum cannabinum*, *Brassica juncea*, *Helianthus annus, animals, Medicago sativa, Melastoma malabathricum, Nephrolepis exaltata, Pteridium esculentum* etc.), animals, like earthworms, enchytraeids and mites, bacteria: *Bacillus*, *Corynebacterium, Staphylococcus, Streptococcus, Shigella, alcaligenes*, *Acinetobacter*, *Escherichia*, *Klebsiella* and *Enterobacter*, and fungi: *Mucor*, *Cunninghamella*, *Rhizopus*, and other Zygomycota, which utilize sugars and other simple soluble nutrients. These pioneer fungi grow rapidly, have a short exploitative phase, and a high competitive ability; they are generally characterized by high tolerance to environmental stresses such as the presence of pollutants, in fact, they are common in polluted soils. In general bioremediation provides a technique for cleaning up pollution by enhancing the natural biodegradation processes. Regardless of which aspect of bioremediation that is used, this technology offers an efficient and cost effective way to treat contaminated soil.

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Bioremediation, contaminated soil, heavy metal, hydrocarbons, pollutant.

Introduction

Due to global industrialization, war, and nuclear processes a large amounts of toxic compounds have been released into the biosphere. The heavy metals released through the various industries as effluent, nuclear radiation and releases of heavy metals by other process in the environment may contaminate the soil. The soil contaminate were divided into two major classes i.e. inorganic and organic. Inorganic pollutants comprises of heavy metals such as arsenic, cadmium, mercury, and lead while organic contaminants include petroleum, hydrocarbons, phenolic compounds, fertilizers, herbicides, and pesticides (Zhang *et al.,* 2020)

Bioremediation is a natural process which relies on bacteria, fungi, plants and soil animals to alter contaminants as these organisms carry out their normal life functions. Metabolic processes of these organisms are capable of using chemical contaminants as an energy source, rendering the contaminants harmless or less toxic products in most cases. Thus, bioremediation provides an alternative tool to destroy or render the harmful contaminants through biological activity and this method is also cost effective (Kour *et al.,* 2021). Intensification of agriculture and manufacturing industries has resulted in increased release of a wide range of xenobiotic compounds to the environment. Excess loading of hazardous waste has led to scarcity of clean water and disturbances of soil thus limiting crop production. Bioremediation uses biological agents, mainly microorganisms i.e. yeast, fungi or bacteria to clean up contaminated soil and water. This technology relies on promoting the growth of specific micro flora or microbial consortia that are indigenous to the contaminated sites that are able to perform desired activities. Establishment of such microbial consortia can be done in several ways e.g. by promoting growth through addition of nutrients, by adding terminal electron acceptor or by controlling moisture and temperature conditions. In bioremediation processes, microorganisms use the contaminants as nutrient or energy sources (Quintella *et al.*, 2019). The population explosion in the world has resulted in an increase in the area of polluted soil and water. As the number of people continues increasing day by day it also brings with it a growing pressure on our natural resources i.e. air, water and land resources. In order to outfit to the demands of the people, the rapid expansion of industries, food, health care, vehicles, etc. is necessary. But it is very difficult to maintain the quality of life with all these new developments, which are unfavorable to the environment in which we live, if proper management is not applied. In nature there are various fungi, bacteria and microorganisms that are constantly at work to break down organic compounds but the question arises when pollution occurs, who will do this clean up job. Since the quality of life is inextricably linked to the overall quality of the environment, global attention has been focused on ways to sustain and preserve the environment. The types of contaminants that Environmental Biotechnology investigators have expertise with include chlorinated solvents, petroleum hydrocarbons, polynuclear aromatic hydrocarbons, ketones, TNT, inorganic nitrogen (NO_3, NH_4), Tt,, Pu, Np, Cr, U and other heavy metals. Bioremediation is the term used to describe biological strategies applicable to repair of damaged environment using biological factors. In the case of oil spills, the process exploits the catabolic ability of microorganism feeding on oil. Several workers Zhang *et al.*, (2020) have described various application of microorganism in the bioremediation of oil pollution with encouraging results. Microorganisms can release enzymes in soil and the enzymes have the ability to catalyze the oxidation of a variety of different hydrocarbons indicated by their broad substrate specificities. The enzyme activity of soil is the sum of the activity of al1 accumulated enzymes. The native enzyme activity is the result of many processes which lead to partial incorporation of locally produced enzymes into the soil environment. In other words these enzymes are immobilized at the surface of the soil particles (Sander, 2019). Contamination of soils can result in devastating consequences for plant and animal life that is near the source. In recent years, the negative effects of human waste products on the environment have been recognized and many societies are now seeking to reverse the damage. A few of the many solutions that have been and are being investigated are bioremediation (Feng *et al.*, 2021). The conceptual scope of this review deals with source of soil contaminants, bioremediation as a solution to the soil contamination problem and the role of microorganism on soil remediation.

Source of soil contaminant

In the last few decades, highly toxic organic compounds have been synthesized and released into the environment for direct or indirect application over a long period of time. Fuels, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), pesticides and dyes are some of these types of compounds (Rasheed *et al.*, 2019). Some other synthetic chemicals like radionuclide's and metals are extremely resistant to biodegradation by native flora compared with the naturally occurring organic compounds that are readily degraded upon introduction into the environment. Bioremediation of pollutants utilizing biodegradation abilities of microorganisms include the natural attenuation, although it may be enhanced by engineered techniques, either by addition of selected microorganisms (bioaugmentation) or by biostimulation, where nutrients are added. Genetic engineering is also used to improve the biodegradation capabilities of microorganisms.

Petroleum hydrocarbon

Soil contamination with oil spills is the major global concern today. Soil contaminated with Petroleum has a serious hazard to human health and causes organic pollution of ground water which limits its use, causes economic loss, environmental problems, and decreases the agricultural productivity of the soil (Zhang *et al.*, 2021). The concern stems primarily from health risks, from direct contact with the contaminated soil, vapors from the contaminants, and from secondary contamination of water supplies within and underlying the soil. The toxicity of petroleum hydrocarbons to microorganisms, plants, animals and humans is well established. The toxic effects of hydrocarbons on terrestrial higher plants and their use as weed killers have been ascribed to the oil dissolving the lipid portion of the cytoplasmic membrane, thus allowing cell contents to escape. The most noticeable sources of contamination are releases from manufacturing and refining installations, oil-tanker spills and accidents during transportation of the oil. Crude oils are transported long distance either on land pipeline or on water in tankers and both of which are prone to oil spill and accidents. A great part of the oil pollution problem results from the fact that the major oil-producing countries are not the major oil consumers. It follows that massive movements of petroleum have to be made from areas of high production to those of high consumption (Galitskaya *et al.*, 2021).

Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons are important pollutants classes of hydrophobic organic contaminants (HOCs) widely found in air, soil and sediments. The major source of PAH pollution is industrial production. PAHs are formed and introduced to environment either naturally or anthropogenically. Naturally, PAHs are mainly formed as a result of pyrolytic process, especially the incomplete combustion of organic materials during different human activities, such as processing of coal and crude oil, combustion of natural gas, forest fires, combustion of refuse, vehicle traffic, as well as in natural process such as carbonization and volcanic eruption (Rajput *et al.*, 2021). However, these processes are believed to have relatively small contribution of PAHs in the terrestrial ecosystem. On the other side, anthropogenic sources which are notably increased with the world industrial extension especially during the 20th century. PAHs are introduced into the environment through accidental spillage, misguided disposal of petroleum and creosote wastes, and intensive combustion of fossil fuels, coal, wood preserving products and leaking from underground tanks, etc. (Zhang *et al.*, 2020).

Polychlorinated Biphenyls

Polychlorinated biphenyls are mixtures of synthetic organic chemicals. Due to their non-flammability, chemical stability, high boiling point, and electrical insulating properties, PCBs were used in hundreds of industrial and commercial applications including electrical, heat transfer, and hydraulic equipment; as plasticizers in paints, plastics, and rubber products; in pigments, dyes, and carbonless copy paper; and many other industrial applications. Consequently, PCBs are toxic compounds that could act as endocrine disrupters and cause cancer. Therefore, environmental pollution with PCBs is of increasing concern (Valizadeh *et al.*, 2021). Majority of the PCBs in the environment finds its way during their manufacturing, usage as well as during disposal. This can be in the form of spillages and leakages during production, transportation and other exposure units. Other sources of PCB emission include treatments, storage, disposal facilities and landfills; hazardous waste sites; steel and iron reclamation facilities like auto scrap burning as well as in accidental release of PCB to the atmosphere (Stella *et al.*, 2017).

Pesticides

Pesticides are substances or mixture of substances intended for preventing, destroying, repelling or mitigating any pest. The term pesticide covers a wide range of compounds including insecticides, fungicides, herbicides, rodenticides, molluscicides, nematicides, plant growth regulators and others. Pesticides which are rapidly degraded are called non persistent while those which resist degradation are termed persistent (Sander, 2019). The need to produce a greater quantity and quality of food by pest control resulted in intensive use of pesticides over the last 50 years. Pesticides are chemicals used by the very man to control agricultural pests and their correct application is the most accepted and effective for maximum production and quality of crops (Mamirova *et al.*, 2021). The increasing use and improper handling of these substances have raised concerns about the risks and damage that could result in the economy, the environment and public health most of the time pesticides poisoning represent problems for handlers, implement or work with these products.

Dyes

Dyes are widely used in the textile, rubber product, paper, printing, color photography, pharmaceuticals, cosmetics and many other industries. Azo dyes, which are aromatic compounds with one or more (–N=N–) groups, are the most important and largest class of synthetic dyes used in commercial applications. These dyes are poorly biodegradable because of their structures and treatment of wastewater containing dyes usually involves physical and / or chemical methods such as adsorption, coagulation-flocculation, oxidation, filtration and electrochemical methods (Khan and Malik, 2018). The success of a biological process for color removal from a given effluent depends in part on the utilization of microorganisms that effectively decolorize synthetic dyes of different chemical structures.

Radionuclides

Radionuclides exist in the environment either naturally or artificially. It has been estimated that, on average, 79% of the radiation to which humans are exposed is from natural sources, 19% from medical application and the remaining 2% from fallout of weapons testing and the nuclear power industry. However, most of the public concern over radiation from radionuclides has been due to the global fallout from atmospheric nuclear weapons testing and the operation of nuclear facilities. Both of these activities have introduced a substantial amount of manmade radionuclides into the environment and have caused radionuclide contamination of large areas of land worldwide. Contamination of soils with typical fissions product radionuclides, such as 137Cs and 90Sr, has persisted for far longer than was originally expected. A radionuclide is an atom with an unstable nucleus, characterized by excess energy available to be imparted either to a newly created radiation particle within the nucleus or via internal conversion. During this process, the radionuclide is said to undergo radioactive decay, resulting in the emission of gamma ray(s) and/or subatomic particles such as alpha or beta particles (Kropacheva *et al.*, 2021).

Heavy metals

Inappropriate and careless disposal of industrial waste often results in environmental pollution. The pollution includes point sources such as emission, effluents and solid discharge from industry, vehicle exhaustion and metal smelting or mining, as well as nonpoint sources each of the sources have their own damaging effects on plant, animal and human health, but those that add heavy metals to soils are of serious concern due to the persistence of these elements in the environment and they cannot be destroyed, but are only transformed from one state to another (Zhang *et al.*, 2021). Nevertheless, human activity and mostly chemical industry, mining and metallurgy, as well as municipal management and traffic emissions are the main source of environmental pollution. Some authors also mention that waste disposal, waste incineration, fertilizer application and long-term application of wastewater in agricultural lands may result in heavy metal pollution of soils. Heavy metals occur naturally in soils due to pedogenetic processes of weathering parent materials, however concentrations of these metals are regarded as trace (<1000 mg×kg-1) and rarely toxic due to the disturbance and acceleration of the natural slow geochemical cycles of metals by man, most soils of rural and urban environments accumulate one or more heavy metals above the defined background levels, high enough to cause risks to ecosystems Nevertheless, heavy metals occurring in soils from anthropogenic sources tend to be more mobile, therefore more bioavailable than pedogenic or lithogenic ones. Communication routes, such as roads, railways etc., are an important source of soil pollution, especially in the case of lead and zinc. Despite restricted use of leaded gasoline adopted in most countries, lead remains one of the most serious automotive-originating metal pollutants. The areas located nearby roads, particularly in urban sites, are the most vulnerable to automotive pollution. Apart from lead and zinc, chromium, cadmium, nickel and platinum are among the pollutants emitted by combustion engine-powered vehicles. Heavy Metal Pollution on Microbial Abundance and Diversity in Soils, Zn has been found in plants and soils adjacent to smelting plants. Another major source of soil pollution is the aerial emission of lead from combustion of petrol containing tetraethyl lead; this contributes substantially to the content of Pb in soils in urban areas and in those adjacent to major roads (Rajput *et al.*, 2021). Another, and one of the most significant sources of heavy metal pollution of soils, includes heavy industry, e.g. mining and metallurgy. Industrial airborne heavy metal contamination of the nonferrous smelters surrounding landscapes is a well-known and widely occurring phenomenon. The fine fractions of dust are enriched with lead, arsenic, and zinc. The quantity and composition of dust derived from different sources (metallurgical processes) varies according to the raw materials and the condition of the gas cleaning systems. The cause for the frequently widely dispersed metal pollution in habitats of mining areas was found in the formation of acid mine drainage (AMD). The runoff from mining heaps of active and abandoned mines can be extremely acidic, with pH values reaching as low as pH 2 chemical and biological oxidation of the abundant mineral pyrite (FeS2) occurs after the unearthing of pyrite-containing rock formations and results in an acidification of the dump material (Rajput *et al.*, 2021) Under acidic conditions, the majority of heavy metals is leached from the waste dump and they are transported as AMD in stream waters and galvanization industry may cause soil pollution with silver as well as other industrial facilities that use silver salts. Additionally, the increased amount of silver may by introduced to soils with municipal sewage. Municipal sewage contains also large amounts of highly soluble forms of zinc, which may then easily contaminate soil environment and zinc is also extensively used in metallurgical industry, as an anticorrosion agent in alloys and in galvanization. It is frequently used in paint industry. The concentration of cadmium highly increases in soils polluted with emissions from nonferrous metal plants, which constitute over 60% of all anthropogenic sources of this element in soils. Municipal sewage contains on average 10 – 40 ppm of cadmium, while industrial sewage may contain over 1000 ppm. This is also a case of large amounts of lead that may be introduced into soils from municipal sewage and waste, as they contain mobile forms of this element. This may result in large increase in the concentration of lead in soils that may exceed several times the admissible limits. Additionally, dust emissions from landfills of nonferrous metal plants may become dangerous sources of lead in soils. Standard agricultural practices are also a significant source of heavy metals in soils, as application of fertilizers and pesticides has contributed to a continuous accumulation of these elements (Zhang *et al.*, 2020). Heavy metals can accumulate in soils due to the application of liquid and solid manure, as well as inorganic fertilizers. The application of numerous biosolids, such as livestock manures, composts and municipal sewage sludge on agricultural soils leads to the accumulation of various heavy metals, such as, Cd, Cr, Cu, Hg, Mo, Ni, and Zn (Sharma and Kumar, 2021).

Types of Bioremediations

Nowadays, several bioremediation techniques have been applied for contaminated soil treatment. For instance, these remediation techniques can be carried out either on the site or out of it. According to EPA (Environmental Protection Agency) on the basis of removal and transportation of wastes for treatment there are basically two methods. These are in-situ bioremediation ex-situ bioremediation.

In-situ bioremediation

Is the treatment of contaminant without removal/ excavation of the contaminated soil In situ methods are suited to instances where the contamination is widespread throughout, and often at some depth within, a site, and of low to medium concentration (Wang *et al.*, 2020). This type of remediation is considered less expensive since it does not include the excavation fees. Moreover, dust release or volatilization of the contaminants could be avoided; however, it is characterized by its slow action especially. Some of *in-situ* bioremediation methods include:

Bioventing

Bioventing is an in-situ remediation technology that uses indigenous microorganisms to biodegrade organic constituents adsorbed to soils in the unsaturated zone. Soils in the capillary fringe and the saturated zone are not affected. In bioventing, the activity of the indigenous bacteria is enhanced by inducing air (or oxygen) flow into the unsaturated zone (using extraction or injection wells) and, if necessary, nutrients can also be added to the soil to stimulate the growth and metabolism of the indigenous species. The process is similar to soil vapour extraction (SVE). However, while SVE removes constituents primarily through volatilization, bioventing systems promote biodegradation of constituents and minimize volatilization (generally by using lower air flow rates than for SVE) (Sharma, 2019).

Bioaugmentation

This process involves the introduction of exogenous species or enzymes into a contaminated soil to stimulate the degradation of organic pollutants present in the soil. The introduced culture from outside are assumed to have valuable specific degradation capacities or serving as donors of catabolic genes that accelerate the degradation rate within short period. The introduced microorganisms must remain viable and should compete with the microorganisms already existing in the system (Pal, 2020). A number of inoculants which specifically degrade various xenobiotic compounds are commercially available.

Biostimulation

Biostimulation involves the introduction of nutrients or substrates such as fertilizers or different organic co-substrates, to stimulate the growth and metabolism of the indigenous species performing the biodegradation of pollutants. Substrates containing nitrogen and phosphorous are the most commonly used stimulants due to their electron acceptor capabilities.

Also it may involve the addition of electron acceptors or electron donors to increase the numbers or stimulate the activity of indigenous biodegradative microorganisms (Pal, 2020).

Ex-situ Bioremediation

In this remediation technique, the contaminated soil is removed from its origin to another site for treatment. This description applied whether the material is taken to another venue, or simply to another part of the site (in site). These treatments could be better controlled and monitored; as a result, normally less time is required compared with *in-situ* treatments. Nevertheless, excavation and transport costs make it less cost-effective. These treatments include:

Bioslurry system (bioreactor)

Bioslurry system (bioreactor) is accomplished by combining the excavated soil with water and other additives. The soil is treated in a controlled bioreactor where the slurry is mixed to keep the solids suspended and microorganisms in contact with the contaminant, where normally the biodegradation occurs at a rapid rate (Khan *et al.*, 2018).

Land farming

Land farming involves the excavation of the contaminated soil and spreading it on thin layers (no more than 1.5m). Biodegradation of pollutants is stimulated aerobically by aeration and/or the addition of nutrients, minerals and water to promote the growth of the indigenous species (Kulshreshtha *et al.*, 2014).

Biopiles

Biopiles also known as bioheaps, compost cells or biocells, used for the remediation of excavated contaminated soil. This technology involves the piling of contaminated soil into piles or heaps and the stimulation of aerobic microbial activity either through aeration or the addition of nutrients, minerals or moisture. A typical height of biopiles can be up to 6m. Biopiles are similar to land farming due to the fact that this technology also uses oxygen as a way to stimulate bacterial growth. But the latter is aerated through tilling or blowing, where biopiles are aerated by forcing air to move by injection through perforated piping placed throughout the pile (Sharma, 2019).

Composting

Composting bioremediation relies on the mixing of the contaminated soil with another organic amendment, wherein as the organic amendment matures, the pollutants are degraded by the active microorganisms within the matrix. In addition, the organic amendment provides nutrients for the soil indigenous microflora which along with the introduced microorganisms through the amendment will degrade the target contaminants (Quintella *et al.*, 2019). In fact, composting treatment holds the potential to serve as a low-cost method of treating hazardous waste with minimal environmental controversy; however, information is lacking regarding the treatability of various toxicants and optimum conditions for treatment.

Organisms involved in bioremediation and their roles

Plants

There are approximately 400 plant species from 45 different families which act as a hyperaccumalator plants. Plant species for phytoremediation should be selected to ensure that the roots can expand throughout the entire contaminated zone. A number of criteria for selecting plants were identified for phytoremediation

Animals

There are deferent types of soil animals, like earthworms, enchytraeids and mites, do have positive effects on the process by utilizing organic compounds in their own metabolism, and more importantly, by increasing metabolic activity of soil microbes. Soil animals can also be exploited in remediation and reclamation processes, they can take part in the process, increasing overall, and especially microbial, metabolic activity of the soil. The earthworms derive its name from the fact that it burrows and eats its way into the earth and have been on the earth for over 20 million years. There are 3920 species of earthworms distributed throughout the world (*Zeb et al.*, 2020). Earthworms are the dominant soil animal invertebrate in soils that might represent 60-80% of the total soil biomass which exert significant impact on the distribution and activities of soil microflora organic matter dynamics, plant growth, modification of soil structures by burrowing and chemical transport and moisture retention through ingesting, burrowing, and casting activities. The earthworm's sphere of influence is known as drilosphere ecosystem including burrow systems, surface and belowground earthworm casts, earthworm intestine and associated processes with its gut and cast. One of the benefits of earthworm activity is releasing the unavailable pollutants in way to enhance the bioremediation performance. As a mechanism of digestion, earthworms ingest contaminants and in their foregut (crop), all the way to their hindgut they digest the soil and contaminants, thus they increase the contact surface between the ingested microflora and the contaminants. Several literatures have studied certain species of earthworms such as *Eisenia fetida, Aporrectodea tuberculata, Lumbricus terrestris, Lumbricus rubellus, Dendrobaena rubida, Dendrobaena veneta, Eiseniella tetraedra, Allobophora chlorotica,* and *P. excavatus* for their ability to remove heavy metals, pesticides and lipophilic organic micropollutants like the polycyclic aromatic hydrocarbons (PAHs) from the soil (Liu *et al.,* 2020).

Bacteria

There are many reports on the degradation of environmental pollutants by different bacteria. Several bacteria are even known to feed exclusively on hydrocarbons. Bacteria with the ability to degrade hydrocarbons are named hydrocarbon-degrading bacteria. Biodegradation of hydrocarbons can occur under aerobic and anaerobic conditions, it is the case for the nitrate reducing bacterial strains *Pseudomonas* sp. and *Brevibacillus* sp. isolated from petroleum contaminated soil 25 genera of hydrocarbon degrading bacteria were isolated from marine environment. Furthermore, among 80 bacterial strains Biodegradation: Involved Microorganisms and Genetically Engineered Microorganisms isolated which belonged to 10 genuses as follows: *Bacillus, Corynebacterium, Staphylococcus, Streptococcus, Shigella, Alcaligenes, Acinetobacter, Escherichia, Klebsiella* and *Enterobacter*, *Bacillus* was the best hydrocarbon degrading bacteria. Bacterial strains that are able to degrade aromatic hydrocarbons have been repeatedly isolated, mainly from soil. These are usually gram negative bacteria; most of them belong to the genus *Pseudomonas*. The biodegradative pathways have also been reported in bacteria from the genera *Mycobacterium, Corynebacterium, Aeromonas, Rhodococcus* and *Bacillus* (Feng *et al.,* 2021). Both, anaerobic and aerobic bacteria are capable of biotransforming PCBs. Higher chlorinated PCBs are subjected to reductive dehalogenation by anaerobic microorganisms. Lower chlorinated biphenyls are oxidized by aerobic bacteria Research on aerobic bacteria isolated so far has mainly focused on Gram-negative strains belonging to the genera *Pseudomonas, Burkholderia, Ralstonia, Achromobacter, Sphingomonas* and *Comamonas*. However, several reports about PCB-degrading activity and characterization of the genes that are involved in PCB degradation indicated PCB-degrading potential of some Gram-positive strains as well (genera *Rhodococcus, Janibacter, Bacillus, Paenibacillus* and *Microbacterium*) (Valizadeh *et al.,* 2021). Recent findings concerning pesticide degrading bacteria include the chlorpyrifos degrading bacterium *Providencia stuartii* isolated from agricultural soil and *Bacillus, Staphylococcus* and *Stenotrophomonas* from cultivated and uncultivated soil able to degrade dichlorodiphenyltrichloroethane. Researches on bacterial strains that are able to degrade azo dyes under aerobic and anaerobic conditions have been extensively reported. Bacteria consisting of *Proteus* sp., *Pseudomonas* sp. and *Enterococcus* sp. in biodegradation and decolorisation of dye. However, several researchers have identified single bacterial strains that have very high efficacy for removal of azo dyes; it is the case of *Shewanella decolorations* (Galitskaya *et al.*, 2021). Heavy metals biomethylated by a number of different bacterial species *Alcaligenes faecalis*, *Bacillus pumilus*, *Bacillus* sp., *P. aeruginosa* and *Brevibacterium iodinium* to gaseous methyl mercury.

In addition to redox conversions and methylation reactions, acidophilic iron bacteria like *Acidithiobacillus ferrooxidans* and sulfur oxidizing bacteria are able to leach high concentrations of As, Cd, Cu, Co and Zn from contaminated soils Although, many microorganisms are capable of degrading the crude oil present in the soil, it has been found beneficial to employ mix culture opposed to pure cultures in bioremediation as it shows the synergistic interactions. Bacteria for hydrocarbon decomposition are commercially available as freeze dried bacteria, which can be used for bioremediation Bacterias that can degrade petroleum products are-*Pseudomonas, Aeromonas, Moraxella, Beijerinckia, F lavobacteria, chrobacteria, Nocardia,Corynebacteria, Atinetobacter, Mycobactena, Modococci, Streptomyces, Bacilli, Arthrobacter, Aeromonas, Cyanobacteria* etc (Thapa *et al.,* 2012).

Table.1 Plant organisms widely used and studied in bioremediation

Genus/species	Toxic Chemicals/Elements
Ambrosia artemisifolia	Pb
Apocynum cannabinum	Pb
Brassica juncea	Se, Pb and Cu
Helianthus annus	As and Ur
Medicago sativa	Benzopyrene, PAEs and PAHs
Melastoma malabathricum	Al
Nephrolepis exaltata	Hg
Pteridium esculentum	As
Pteris vitata	As, Hg, Cs and Sr
Salix viminlais	Cd, Zn and Cu
Raphanus sativu s	Cu
Silene vulgaris	Zn and Cd
Thlaspi caerulescens	Cd and Zn

Source: Rajput *et al.,* (2021)

Fungi

Fungal diversity is globally estimated to 1.5 million species and consists of an incredibly diverse group of organisms. Organisms studied by mycologists include members of the fungal Kingdom but also others like Protozoa e.g. slime moulds. The Kingdom of Fungi is divided into three major classes: the zygomycetes, the ascomycetes and the basidiomycetes. The spatial distribution and metabolic activity of soil microorganisms is heteroge-neous and closely correlated to organic matter availability, which is often concentrated in hot spots. In this contest, fungi with high sporulation capability, such as mitosporic fungi (Deuteromycetes) and Zygomycetes, can easily straggle to reach the suitable environmental condition and nutrients for their growth. When the environment is unsuitable for growth (low nutrients, presence of metabolites, etc.), their asexual spores, called conidia, show an exogenously imposed dormancy induced by the phenomenon termed fungistasis, allowing the fungus to survive (Quintella *et al.,* 2019). Some few investigations have focused on the spatial heterogeneity of pollutants biodegradation, finding that it mainly occurs between the topsoil (an organic rich layer which corresponds to the root zone), the rhizosphere, and the rhizoplane. Since bioremediation activity in this microhabitat seems to be mainly ascribable to the action of its fungal component, it is of crucial importance to deepen the ecological and physiological characteristics of fungi that live in this part of the soil (Stella *et al.,* 2017). Among pioneer saprotrophic fungi there are several species of *Mucor*, *Cunninghamella*, *Rhizopus*, and other Zygomycota, which utilize sugars and other simple soluble nutrients. These pioneer fungi grow rapidly, have a short exploitative phase, and a high competitive ability; they are generally characterized by high tolerance to environmental stresses such as the presence of pollutants, in fact, they are common in polluted soils. Independently by their degradation capabilities, these fungi are capable to decrease the concentration of organic pollutants such as PAH, by accumulating them in intracellular lipid vesicles. Moreover, these vesicles could have a role in biodegradation too (Kour *et al.,* 2021). This accumulation activity can also be common to polymer-degrading fungi that have an extended phase of growth on the major structural polymers such as cellulose, hemicelluloses, or chitin these fungi tend to defend the resource against potential invaders, either by sequestering critically limiting nutrients or by producing inhibitory metabolites. Species belonging to the genera *Trichoderma, Fusarium, Penicillium, Stachybotrys, Aspergillus, Cladosporium, Mortierella, Beauveria, Engyodontium* are some examples of this kind of fungi that have been recently described as tolerant to pollutants such as PCBs, chlorobenzoic acids (CBA), and endosulfan and that are indicated as potential bioremediation agents in soil (Valizadeh *et al.,* 2021). Fungi that degrade recalcitrant polymers often predominate in the later stages of decomposition. The ecological success of fungi that develop later in the decomposition sequence is related to their specialized ability to degrade polymers such as lignin and keratin Among them, *Fusarium, Penicillium, Aspergillus, Paecilomyces, Microsporum, Acremonium, and Geomyces* are often reported as xenobiotics degrading (Anastasi *et al.,* 2013).

Bioremediation provides a technique for cleaning up pollution by enhancing the natural biodegradation processes. So by developing an understanding of microbial communities and their response to the natural environment and pollutants, expanding the knowledge of the genetics of the microbes to increase capabilities to degrade pollutants, conducting field trials of new bioremediation techniques which are cost effective, and dedicating sites which are set aside for long term research purpose, these opportunities offer potential for significant advances. There is no doubt that bioremediation is in the process of paving a way to greener pastures. Regardless of which aspect of bioremediation that is used, this technology offers an efficient and cost effective way to treat contaminated soil. Its advantages generally outweigh the disadvantages, which is evident by the number of sites that choose to use this technology and its increasing popularity. Once again thanks to the bioremediation technology to clean up the polluted environment and therefore may be used as management tool.

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