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Restoration of Contaminated Agricultural Soils Through Utilization of Beneficial Microbes for Global Future Generation

Kamal Prasad* and Kavita Yadav
Absolute Biologicals, Plant Life Science Research, Division of Microbiology, 5th Floor, Sector 44, Delhi NCR, Gurugram, Haryana 122002, India.

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***Corresponding author:** Kamal Prasad, Absolute Biologicals, Plant Life Science Research, Division of Microbiology, 5th Floor, Sector 44, Delhi NCR, Gurugram, Haryana 122002, India.

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Abstract:

Soil is one of all, most precious resources because it supports a variety of significant biological activities and ecosystem services. Unfortunately, soils are currently contaminated globally with various uses of harmful inorganic chemicals and other various human activities that are not environmentally sustainable. From the mining of raw materials to production, transportation, end-user use, disposal, or accidental release of chemicals, the soil is often contaminated for the purpose of threatening human life, livestock, wildlife, and entire ecosystems. Traditional soil cleaning and decontamination processes are very expensive and labor-intensive and didn't perpetually ensure that contaminants are completely removed, and often result in dramatic changes in physical, chemical, and biological characteristics. As a result, more sustainable and innovative technologies have emerged in recent decades. Biological soil remediation strategies known as soft remediation alternatives are being developed to combine (i) effective removal of soil contaminants (ii) reduction of soil ecotoxicity and (iii) minimization of legally and ethically required risks for the environment and human health. Any soil remediation methodology should not solely scale back the concentration of contaminants within the soil below regulative limits, however, conjointly restore soil health and supply crucial scheme services. The microorganisms have shown promising results in the rehabilitation of soils modified with heavy metals and radionuclides, inorganic chemicals such as excessive use of chemical fertilizers, trichloroethylene (TCE), trinitrotoluene (TNT), pesticides including atrazine and organophosphates. The treatment of a wide range of environmental contaminants, environmentally friendly technology, and at low cost compared to methods less expensive than conventional methods. The current manuscript focuses on restoring contaminated agricultural soil using beneficial microbes for a sustainable future generation.

Keywords: bioremediation; heavy metal; pesticides; microorganism; organophosphates

1. Introduction:

Contamination of soil owing to numerous anthropogenic activities is a serious concern all over the world. Increased release of a wide spectrum of xenobiotics has occurred from the intensification of agriculture and the expansion of enterprises. These toxins injure humans, animals, wildlife, crops, and native plants, causing ecological issues and a natural balance to be disrupted. Scientists from all over the world are working to find a solution using a variety of methods, including physical, chemical, and thermal procedures, as well as excavation and transfer of contaminated soil. Unfortunately, those procedures are costly and labor-intensive, do not always assure that pollutants are totally removed or eliminated, and frequently result in dramatic changes in the treated soil's physical, chemical, and biological features. Bioremediation techniques evolved as a result of the search for alternatives to established methods of cleaning polluted places. Bioremediation techniques have attracted a lot of attention, and a lot of research has been done and published on the use of diverse microorganisms for decontamination of various types of pollutants in soil. However, further research is needed to obtain a thorough grasp of present strategies, as well as to modify them appropriately to get the most out of them while also exploring new possibilities based on day-to-day experiences.

2. Health:

Soil health is often defined as "the capacity of a given soil to perform its functions as a living system capable of sustaining biological productivity, promoting environmental quality, and maintaining plant and animal health" (Doran et al. 2000). Soil contamination, along with other degradation processes, can have a negative impact on soil health (Gomez et al. 2012). However, the soil is a hugely complex environmental matrix that serves a variety of, often competing, roles from both an ecocentric and anthropocentric perspective, necessitating the study of many distinct factors in order to accurately measure soil health. Most importantly, to appropriately assess soil health: Physical, chemical, and biological properties with potential as indicators of soil functioning must always be included in the assessment (after all, physical, chemical, and biological processes in the soil ecosystem are not independent but interactive processes); (ii) chemical, (eco)toxicological, and ecological approaches must be incorporated into the evaluation; (iii) the intended use for the contaminated site must be carefully considered, as the very concept of contaminated sites must be taken into account; (iv) the system's inherent temporal and spatial variability (i.e., spatial heterogeneity, temporal dynamics), as well as the scale of both soil processes and the assessment itself, must be considered; and (v) a suitable (inevitably, often far from perfect) "healthy" reference soil should be identified for comparison and target-setting purposes. Soil physicochemical qualities such as pH, redox potential, organic matter content, texture, and others are important parameters that can significantly affect contaminant bioavailability and, hence, (eco)toxicity in soil. Unfortunately, under most environmental legislation, the overall concentration of contaminants is the most important component in contaminated soils Environmental Risk Assessment (ERA). However, such a factor (total soil contaminant concentration) is insufficient to appropriately analyze or quantify the possible negative impact of pollutants on soil functioning (Alvarenga et al. 2018). In reality, soil pollutants' mobility and bioavailability are both important factors in their uptake by organisms and, as a result, their (eco)toxicity (Vamerali et al. 2010; Megharaj et al. 2011). Contaminant bioavailability is a considerably more important element for adequate soil protection and risk assessment than total contaminant concentrations since it represents the fraction that can be taken up by soil organisms and/or leached to other environmental compartments. Metal bioavailability is primarily influenced by physicochemical features of the soil, such as pH, redox potential, moisture content, organic matter content, clay content, anionic compound presence, and so on (Vangronsveld 1998). Organic pollutants' bioavailability and mobility are largely determined by their solubility, hydrophobicity, and interaction with the mineral and organic fractions of the soil matrix via physicochemical processes such as sorption and complexation (Megharaj et al. 2011). As a result, when assessing soil health and, in particular, when choosing a soil remediation option and monitoring the success of the chosen remediation process, it is advised to always include the assessment of the bioavailable fraction of the pollutants. Despite this, there is no agreement on the optimal method for reliably estimating soil pollutant bioavailability. Chemical extractants, such as inorganic salts like $NaNO_3$, $(NH_4)_2SO_4$, and $CaCl_2$, are the most widely accepted approach for metallic pollutants (Vazquez et al. 2008). In any case, biological indicators are essential for a proper assessment of the impact of soil pollutants on soil health, in addition to total and bioavailable contaminant concentrations, because they directly represent the influence of contaminants on the soil biota (Alvarenga et al. 2018). Microorganisms have a significant role in many soil activities and the provision of ecosystem services, while also providing ecologically valuable information that incorporates numerous environmental elements (Jeffery et al. 2010). Similarly, standardized (eco)toxicological bioassays with model organisms such as *Eisenia fetida* (Irizar et al. 2015), *Vibrio fisheri* (Abbas et al. 2018), *Lactuca sativa* (Valerio et al. 2007), and *Cucumis sativus* have been created and proposed for soil (eco)toxicity research.

3.Source of Pollutants in Soil:

Soil pollution is characterized as the accumulation of persistent poisonous substances, chemicals, salts, radioactive elements, or disease-causing agents in soils, all of which have negative impacts on plant development and animal health. Soil pollution can occur in a variety of ways, including seepage from a landfill (Adrian and Arnett 2007), discharge of industrial waste into the soil (Alloway 1995), percolation of contaminated water into the soil (Ang et al. 2005), rupture of underground storage tanks (April and Sims 1995), and excessive application of pesticides, herbicides, or fertilizer (Ackerman 2007). Table 1 lists the most well-known compounds that contribute to soil pollution. Environmentalists around the world are trying to overcome such a huge load of pollutants in soil by several means.

Heavy metal/ trace elements	**Pesticides involved**	**Radionuclides**	**Munition waste**	**Others**
Arsenic, Cadmium, Chromium, Cobalt, Copper and Mercury	Organophosphates, Aldrin and Atrazine	Cesium, Strontium, Potassium, Thorium	Trinitrotoluene	Trichloroethylene, Pentachlorophenol

Table 1: Compounds that contribute to soil pollution.

4.Applications and Technologies for Biological Soil Remediation:

Traditional Physico-chemical and chemical approaches for pollutant cleaning are frequently prohibitively costly. Furthermore, the amount of space accessible for disposal and storage is decreasing. Traditional clean-up procedures have a number of drawbacks, one of which is that, despite their high costs, they may not always assure that toxins are totally removed. As a result, the hunt for cost-effective and environmentally sound alternatives to traditional garbage disposal systems has exploded in the last two decades. Waste-related research, technological development, and implementation are now among the fastest-growing activities in the world. The most promising technologies are those that closely resemble time-tested, natural systems that have successfully restored ecosystems to their native states following undesired disruptions. Natural processes change, eliminate, remove, or otherwise stabilize chemicals from natural sources (animal, vegetable, or mineral) such that they do not accumulate to levels that endanger ecosystem balance or sustainability. Growing public awareness and concern about environmental pollution prompted government and business to collaborate on the development of safe and cost-effective waste management alternatives. Bioremediation has emerged as the most desirable strategy for cleaning up numerous environmental toxins among the technologies that have been explored. Bioremediation is a method for destroying or rendering harmless different pollutants through natural biological activity. As a result, it employs low-cost, low-technology approaches that are widely accepted by the public and may often be carried out on-site. Bioremediation is the process of degrading environmental pollutants into less hazardous forms using living creatures, typically bacteria. It degrades or detoxifies pollutants that are harmful to human health and/or the environment using naturally occurring bacteria, fungus, or plants. The microorganisms could be native to the contaminated location, or they could have been isolated elsewhere and transported to the contaminated site. Living organisms change contaminant substances through reactions that occur as part of their metabolic activities (Vidali 2001). Microorganisms must enzymatically attack contaminants and transform them into harmless compounds for bioremediation to be effective. Because bioremediation is only effective when environmental conditions allow for microbial growth and activity, it is frequently used to manipulate environmental factors to speed up microbial growth and degradation. pH, temperature, and moisture all have an impact on microbial growth and activity (Prasad 2020). Although microorganisms have been isolated in extreme settings, most of them grow best in a small range of temperatures, making it critical to obtain optimal conditions. If the pH of the soil is too acidic, lime can be used to neutralize it. The rate of many biological reactions is affected by temperature, and for every 10°C increase in temperature, the rate of many of them doubles. The cells, however, die at a particular temperature. In late spring, summer, and autumn, a plastic covering can be utilized to increase solar heating. All living species require access to water; therefore, irrigation is required to reach the ideal moisture level. Optimum environmental conditions for the efficient performance of microorganisms are presented in Table 2.

Table 2: Optimum environmental conditions for efficient performance of microorganisms.

S.no.	Environmental factors	Optimum conditions
1	pH	5.5- 8.5
2	Temperature (°C)	15-45
3	Moisture	25-28% water holding capacity
4	Soil type	Low clay or silt content
5	Oxygen	Aerobic, minimum air-filled pore space of 10%
6	Nutrient	N and P for microbial growth
7	Heavy metals	Total content 2000 ppm
8	Contaminants	Not too toxic

5.Strategies for Bioremediation:

Organic contaminants are primarily converted to carbon dioxide, water, and biomass in bioremediation. Some contaminants can be bound to the humic substance fraction and hence immobilized. Degradation can take place in both aerobic and anaerobic environments. The aerobic method, which can be classed as ex-situ or in-situ, is mostly utilized for bioremediation. The amenability of the pollutant to biological transformation, the accessibility of the contaminant to microorganisms, and the ability to optimize biological activity are the three basic principles that guide the selection of appropriate technology among the wide range of bioremediation technologies developed to treat contaminants. The deterioration process is accelerated, and the degree of degradation is improved by using the right technologies and adjusting the circumstances, which lowers the treatment cost (Mohapatra 2008). Ex-situ procedures are those that are used on soil and groundwater that has been removed from a place through excavation (soil) or pumping (groundwater) (water). The term "in situ" refers to treatments that are applied to soil and groundwater on-site with little disturbance. These approaches are the most popular since they are less expensive and cause fewer disruptions because they treat toxins on-site rather than excavating and transporting them. However, the depth of soil that can be adequately treated limits in-situ treatment. Effective oxygen diffusion for optimal rates of bioremediation in many soils extends from a few centimetres to about 30 centimetres into the soil, however, depths of 60 centimetres and greater have been successfully treated in other circumstances (Vidali 2001).

5.1.Ex-situ methods:

Land farming, also known as land treatment or land application, is an above-ground soil remediation process that uses biodegradation to lower organic pollutant concentrations. Aeration and/or the addition of minerals, nutrients, and moisture are commonly used to spread excavated contaminated soils in a thin layer on the ground surface and stimulate aerobic microbial activity inside the soils. Because contaminated soil is treated in thin layers up to 0.4 m deep, a considerable treatment area is required. Ploughing, harrowing, or milling at regular intervals helps to increase degradation by increasing oxygen supply and mixing. The treatment method is cost-effective, and it can be implemented if enough land is available (Mohapatra 2008).

5.1.1. Biopiles:

It's a cross between organic farming and composting. Excavated soils are mixed with soil additives, placed on a treatment area, and bio-remediated with the use of forced aeration. Contaminants are broken down into Carbon dioxide and water. A treatment bed, an aeration system, an irrigation/nutrient system, and a leachate collection system are all part of the basic biopile system. To minimize runoff, evaporation, and volatilization, as well as increase solar heating, soil mounds can be up to 20 feet tall and covered with plastic. Before entering the air stream, volatile organic compounds are treated if necessary (Shukla et al. 2010). Biopiles provide an ideal environment for aerobic and anaerobic bacteria to thrive.

5.1.2. Bioreactors:

Contaminated soil is treated in either a solid or a slurry phase in this method. Solid-phase reactors work on the basis of mechanical degradation of soil through attrition and vigorous mixing of the components in a confined container. Contaminants, bacteria, nutrients, water, and air are all brought into constant contact as a result of this. A slurry bioreactor is a containment vessel and apparatus used to create a three-phase (solid, liquid, and gas) mixing condition to increase the bioremediation rate of soil-bound and water-soluble pollutants as a water slurry of contaminated soil and biomass (usually indigenous microorganisms) capable of degrading target contaminants as a water slurry of the contaminated soil and biomass (usually indigenous microorganisms) capable of degrading target contaminants. Because the enclosed environment is more manageable and hence more controllable and predictable, the pace and amount of biodegradation in a bioreactor system is larger than in situ or in solid-phase systems. However, before being placed in a bioreactor, the contaminated soil must be pre-treated (e.g., excavation) or the contaminant can be removed from the soil via soil washing or physical extraction (e.g., vacuum extraction) (Vidali 2001).

5.1.3. Composting:

It is used in bioremediation to degrade harmful organic molecules and may reduce the toxicity of metallic pollutants found in organic residues, garbage, and by-products. Organic wastes are decomposed by microorganisms in composting, which is comparable to what happens physiologically in soil. Composts have greater temperatures than soils, which leads to enhanced pollutant solubility and metabolic activity. Composts with a lot of substrates can cause organic pollutants to co-metabolize. Mechanical treatment of compostable materials, such as grinding, mixing, and sieving out non-degradable or undesired components like metals, plastics, glass, and stones, creates favorable circumstances for biological treatment. The nature of the organic pollutant, composting conditions and processes, microbial populations, and time all have an impact on the compost mechanism's efficacy (Barker and Bryson 2002).

5.2. In-situ methods:

5.2.1. Biosparging:

It uses and promotes indigenous microbes in saturated soil to break down organic pollutants. Air is introduced into the saturated zone (below the water table) through boreholes to boost the activity of the soil's native microorganisms by increasing oxygen dissolution. Increased oxygen speeds up the aerobic biodegradation of pollutants in the soil or groundwater. Petroleum compounds that are adsorbed to the soil within the capillary fringe, below the water table, or dissolved in groundwater can be reduced through biosparging. Biosparging is often utilized at sites where mid-weight petroleum compounds, such as diesel fuel, are used; lighter petroleum molecules volatilize quickly and are removed quickly through sparging. The permeability of the soil is an important aspect of the technology's efficiency (Vidali 2001; Mohapatra 2008).

5.2.2. Bioventing:

An in-situ remediation technique that employs native microorganisms to biodegrade organic components adsorbing to unsaturated zone soils. It is based on soil vapor extraction with vacuum enhancement. Pressure variations in the subsurface generate an inflow of atmospheric air and, as a result, oxygen supply, which is required for aerobic pollutant decomposition. It works to clean up petroleum products such as gasoline, jet fuel, kerosene, and diesel fuel. If the contaminants to be treated are volatile, the extracted soil vapor must be treated by contaminant adsorption on activated carbon followed by biodegradation in a biofilter (Mohapatra 2008).

5.2.3. Bioaugmentation:

It includes the introduction of microbes, either native or exogenous, too polluted areas. The utilization of additional microbial cultures in a land treatment unit is limited by two factors: nonindigenous cultures rarely compete well enough with indigenous populations to develop and maintain viable population levels, and most soils with long-term exposure to biodegradable waste include indigenous microbes that are good degraders if the land treatment unit is adequately managed (Vidali 2001).

6.Bioremediation of organic pollutants:

In polluted areas, a wide range of organic contaminants are likely to be present, mandating the use of a wide range of microbes for efficient clean-up (Table 3). The first biological remediation agent was patented in 1974, and it was a strain of *Pseudomonus putida* (Prescott et al. 2002). Since then, a huge number of species from at least 11 distinct prokaryotic divisions have been added to the list (Glazer and Nikaido 2007). Microorganisms degrade organic contaminants either in the presence of oxygen (respiration) or under anoxic circumstances (denitrification, methanogenesis, and sulfidogenesis). The bulk of contaminants in the environment degrade most quickly and completely when they are exposed to aerobic conditions. Oxidations, which are catalyzed by oxygenase and peroxidases, are important enzymatic processes in aerobic biodegradation. Oxygenases are oxygen-dependent oxidoreductases that incorporate oxygen into the substrate. Degradative organisms require oxygen at two stages of their metabolism: the initial attack on the substrate and the last stages of the respiratory chain. Soluble carbon molecules are degraded sequentially to methane, carbon dioxide, ammonia, and hydrogen sulfide under strictly anaerobic settings by a synoptic interaction of fermentative and acetogenic bacteria with methanogens or sulfate reducers under strictly anaerobic conditions. In terms of kinetics and capabilities, anaerobic degradation has long been thought to be inferior to aerobic degradation. Anaerobic techniques have proven to be more efficient and less expensive than aerobic treatment when high loads of easily degraded organic pollutants are present.

Pollutants	**Organism**	**Reference**
Benzene, anthracene, hydrocarbons	*Pseudomonas* spp.	Cybulski et al. (2003)
Halogenated hydrocarbons, linear alkyl benzene sulfonates, Polycyclic aromatics (PCBs)	*Alcaligenes* spp.	Lal and Khanna (1996)
Aromatics	*Flavobacterium* spp. *Azotobacter* spp.	Jogdand (1995)
Cycloparaffins, Branched hydrocarbon	*Mycobacterium* spp.	Sunggyu, (1995)

benzene		
Halogenated hydrocarbons	*Corynebacterium* spp.	Jogdand (1995)

Table 3: Potential of micro-organism to degrade various organic pollutants

6.1. Pesticides:

Atrazine and organophosphate are two of the most commonly used organic pesticides in agriculture. In conservation tillage systems, atrazine is the most commonly used herbicide to prevent soil erosion. It was first employed for weed control in the agricultural production of crops such as maize, sorghum, and sugar cane in the 1950s. Atrazine is resistant to biodegradation, with a reported half-life of more than 170 days in soils harboring atrazine-degrading microorganisms and solubility of roughly 30 mg/l (Protzman et al. 1999). Atrazine is commonly detected in surface and groundwater samples due to its tenacity, posing a direct risk to humans through the intake of potable water. Like other triazine herbicides, atrazine works by attaching to the photosystem II protein plastoquinone-binding protein, which animals lack. Starvation and oxidative damage produced by a malfunction in the electron transport mechanism cause plant death. High light intensity accelerates oxidative damage (Arnold et al. 2002). Several studies have called for its restriction in the United States due to its claimed endocrine disruptor effects, probable carcinogenic effect, and epidemiological link to reduced sperm levels in men (Ackerman 2007). *Pseudomonas* sp. ADP has been the most closely investigated of the atrazine-degrading microbes. *Pseudomonas* sp. ADP transforms atrazine to cyanuric acid via the AtzA, B, and C enzymes in the biodegradation of atrazine. T

It converts atrazine to hydroxyatrazine, which is subsequently hydrolytically deamidated to generate N-isopropylammelide. Finally, N-isopropylammelide is converted to cyanuric acid by AtzC, a hydrolytic deamidase similar to AtzB. Enzymes found in soil microorganisms then mineralize cyanuric acid, converting it to carbon dioxide and ammonia. (Ang et al. 2005; Krutz et al. 2009). Over 100 OP pesticides are in use around the world, accounting for 38% of total pesticide usage (Singh 2009). Insecticides and chemical warfare chemicals contain organophosphates, which are highly toxic neurotoxins. The organophosphate family includes paraoxon, parathion, chlorpyrifos disulfoton, ruelene, carbophenothion, and dimension. The ability of this class of chemicals to suppress acetylcholinesterase and, as a result, block acetylcholinesterase from breaking down acetylcholine at the synaptic junction, is primarily responsible for their neurotoxicological effects. These chemicals have also been linked to pathology and chromosomal damage in bladder cancer patients). The most important stage in the detoxification of organophosphates in the soil is microbial degradation by hydrolysis of the P-O alkyl and P-O aryl bonds. The bacteria that degrade the most major organophosphates are listed in Table 4. Phosphotriesterases (PTEs) are a set of enzymes found in microbes, animals, and plants that are responsible for the breakdown of OP. Lots of study has been done on OP biodegradation to date, and as a result, our understanding of OP degradation has evolved significantly in recent years. It is being used for a variety of industrial applications as a result of a greater understanding of the issue (Singh 2009).

S.no.	Organophosphates	Bacteria	Fungi
1	Chlorpyrifos	*Pseudomonas* sp., *Bacillus* sp., *Kurthia* sp., *Streptococcus* sp.	*Aspergillus niger*, *Mucor* sp., *Fusarium* sp., *Claviceps* sp.
2	Diazinon	*Pseudomonas glycinea*, *Pseudomonas diminutum*, *Anthrobacter* sp.	*Aspergillus oryzae*, *Trichoderma* sp.
3	Malathion	*Bacillus cereus*, *Bacillus subtilis*, *Micrococcus* sp., *Rhizobium japonicum*	*Aspergillus* spp., *Penicillium* sp., *Trichoderma viride*
4	Dimethonate	*Pseudomonas Putida*, *Rhizobium sp.*, *Nocardia sp.*	*Claviceps* sp., *Mucor* sp., *Penicillium notatum*
5	Dichlorvos	*Bacillus coagulans*, *Pseudomonas diminutum*, *Pseudomonas fluorescens*, *Pseudomonas melophthora*	*Saprolegnia* sp., *Penicillium notatum*, *Aspergillus niger*

Table 4: Microorganism known for metabolism of organophosphates in culture and in field conditions.

7.Bioremediation of inorganic pollutants:

7.1. Heavy metals:

Heavy metals are the most common inorganic contaminants, and they have contaminated a huge area of land as a result of mining, manufacturing, agricultural, and defense activities. Although metals are naturally present at various quantities in the earth's crust and many metals are required for cell function (e.g. copper, iron, manganese, nickel, zinc), all metals are hazardous at larger amounts. Any metal (or metalloid) species may be deemed a "contaminant" if it exists in an unwelcomed location, or in a form or concentration that harms humans or the environment (McIntyre 2003). Metal concentrations in soil typically range from less than one to as much as 70,000 mg/kg. Regardless of where the metals in the soil came from, high levels of several metals can cause soil deterioration, crop yield decline, and poor agricultural product quality (Long et al. 2002). Heavy metals are a long-term threat to both the environment and human health since they are not biodegradable and may infiltrate the food chain (Jarup 2003). Arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), selenium (Se), silver (Ag), and zinc are among the metals/metalloids included (Zn). Aluminum (Al), cesium (Cs), cobalt (Co), manganese (Mn), molybdenum (Mo), strontium (Sr), and uranium (U) are some of the less frequent metallic species that can be considered pollutants (McIntyre 2003). Pb, one of the most persistent metals, has a soil retention duration of 150–5,000 years and has been shown to sustain high concentrations in soil for up to 150 years after sludge application (NandaKumar et al. 1995). Cd has an average biological half-life of roughly 18 years and a 10-year half-life in the human body (Knasmuller et al. 1998). Another difficulty with hazardous heavy metals is that they can be transported and deposited in the bodily tissues of animals or humans through the food chain, causing DNA damage and carcinogenic effects due to their mutagenic properties (Knasmuller et al. 1998). Some species of Cd, Cr, and Cu, for example, have been linked to health problems ranging from dermatitis to cancer (McLaughlin et al. 1999). Metal ions can fully limit the microbial population at high concentrations by inhibiting numerous metabolic activities such as protein denaturation, cell division inhibition, cell membrane disruption, and so on, or organisms can acquire resistance or tolerance to the heightened levels of metals. Although the speciation and bioavailability of metals may fluctuate with variations in environmental conditions, these metals cannot be destroyed biologically and are hence eternal (Shukla et al. 2010). In microorganisms, metal toxicity is caused by the displacement of critical elements from their native binding sites or by ligand interactions (Nies 1999; Bruins et al. 2000). Hg^{2+}, Cd^{2+}, and Ag^{2+}, for example, tend to attach to SH groups, inhibiting the action of sensitive enzymes (Nies 1999). Metals can also harm cell membranes, affect enzyme specificity, disrupt cellular activities, and destroy DNA structure at high levels (Bruins et al. 2000). Microorganisms have been compelled to evolve metal-ion homeostasis factors and metal-resistance determinants as a result of this (Nies 1999; Bruins et al. 2000). Exclusion through permeability barrier; intra- and extra-cellular sequestration; active efflux pumps; enzymatic reduction; and reduction in the sensitivity of cellular targets to metal ions are six possible mechanisms for a metal resistance system (Ji and Silver 1995; Nies and Silver 1995; Nies 1999; Bruins et al. 2000). Microorganisms (Table 5) can function in metal-contaminated environments because of one or more of these resistance mechanisms. Metal microbial transformations perform a variety of tasks in stressful environments and can be grouped into two major categories: inorganic redox conversions and conversions from inorganic to organic form and vice versa, most often methylation and demethylation. Microbes can obtain energy by oxidizing iron, sulfur, manganese, and arsenic. Metal reduction, on the other hand, can take place by dissimilatory reduction, in which microbes use metals as a terminal electron acceptor in anaerobic respiration. For example, oxyanions of As, Cr, Se, and U (Tebo and Obraztsova 1998) can be used in microbial anaerobic respiration as terminal electron acceptors. In addition, microorganisms may possess reduction mechanisms that are not coupled to respiration but instead are thought to impart metal resistance. For example, aerobic and anaerobic reduction of Cr (VI) to Cr (III); reduction of Se (VI) to elemental selenium (Lloyd et al. 2001); reduction of U(VI) to U(IV) (Chang et al. 2001); and reduction of Hg (II) to Hg (0) (Wagner-Dobler et al. 2000) are widespread detoxification mechanisms among microorganisms. Microbial methylation plays an important role in the biogeochemical cycle of metals because methylated compounds are often volatile. For example, mercury [Hg (II)] can be biomethylated by a number of different bacterial species (e.g. Pseudomonas sp., Escherichia sp., Bacillus sp. and Clostridium sp.) to gaseous methylmercury (Pongratz and Heumann 1999), which is the most toxic and most readily accumulated form of mercury (Nikunen et al. 1990). Biomethylation of arsenic to gaseous arsines (Gao and Burau 1997); selenium to volatile dimethyl selenide (Dungan and Frankenberger 2000); and lead to dimethyl lead (Pongratz and Heumann 1999) has also been observed in a variety of soil environments.

S.no.	**Elements**	**Microorganism**
1	Copper	*Pseudomonas aeruginosa, Chlorella vulgaris, Pleurotus ostreatus, Bacillus sp.*
2	Cobalt	*Zooglea sp., Phormedium valderium*
3	Cadmium	*Citrobacter sp., Aspergillus niger, Ganoderma applantus*, Stereum hisutum
4	Zinc	*Bacillus* sp., *Aspergillus niger, Pleurotus ostreatus*
5	Silver	*Rhizopus arrhizus, Aspergillus niger,* Geobacter metallireducens
6	Mercury	*Volvaricella volvacea, Chlorella vulgaris, Rhizopus arrhizus*
7	Chromium	*Desulfovibrio fructosovorans, Desulfovibrio vulgaris*
8	Nickle	*Zooglea sp., Chlorella vulgaris*

Table 5: Micro-organism that utilizes heavy metals

8.Future prospects and importance of Bioremediation:

Bioremediation is a technique for cleaning up polluted ecosystems such as soils, groundwater, and oceans. Bacteria, fungus, algae, and plant species can all be found in such systems. Toxic substances in their surroundings can be metabolized, immobilized, or absorbed by them. However, one of the key benefits of these systems is that they are less hazardous to the environment and produce little or no by-products. Furthermore, traditional physical and chemical treatments are ineffective and costly, causing more harm than help. As a result, by assessing previous bioremediation research. Bioreactors or products that are more efficient and feasible could be designed. Furthermore, these systems may be able to eliminate all toxins from the environment.

It also produces valuable chemicals as a by-product.

9.Conclusion:

Sustainable biological soil remediation methods that are economically feasible are being developed to: efficiently remove contaminants from soil; reduce their bioavailability, mobility, (eco)toxicity, and potential risks to environmental and human health; and simultaneously restore soil health and ecosystem services. Traditional Physico-chemical approaches for restoring contaminated environments are being replaced by bioremediation. Due to the fact that it is a cost-effective, labour-intensive, safe, and eco-friendly approach, considerable progress and advancements have occurred in this field during the last two decades. However, because bioremediation sometimes incorporates numerous treatment procedures and can endure for a long time (years or decades) and is frequently used in conjunction with other techniques, estimating its success can be challenging. More multidisciplinary research in connection to process optimization, validation, its impact on the environment, and the effectiveness and predictability of the approach should be carried out in this context to make it a widely acknowledged technique.

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