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Rhizoremediation an Important Technique to Clean Environment: A Review.

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Abstract: Nature is the biggest gift to mankind. But due to the increasing urbanization and technological advances, the human race has put a threat to nature by increasing pollution levels. Technological advances have adversely affected all the natural essentials necessary for human survival including soil, water, air, and food. It is thus become very essential to restore nature by using biological methods and techniques. This review article focuses on rhizoremediation and its biotechnological advances for the elimination of pollutants from the environment.

***Keywords* - Microbes, Rhizoremediation, Environment, Metals.**

I. INTRODUCTION:

Mankind and nature are directly associated with each other. Human cannot survive by destroying the nature. With the advancement of technology and urbanization poses a severe threat to the existence of mankind. The most adverse effect is the tremendous rise in pollution. Air, water, soil and space all are polluted with the immense destruction of nature. So now it becomes the need of today to find solution of this threat which comes in our way. Various group of researchers are working to clean up the atmosphere and to restore the naturality of the ecosystem. Rhizoremediation is one of such technique which is used worldwide for the improvement of ecosystem. This technique is highly preferred due to its multiple advantages as it is ecofriendly and economical. The word rhizosphere refers to the environment impacted by plant roots and characterised by increased bacterial activity (Curl et al 1986). Plant roots provide a wide surface area for a big population of bacteria and carry the root-colonizing, remediating microorganism to pollutants 10 to 15 metres deep in the soil, making rhizoremediation an appealing technique (Kingsley et al 1994: Scott et al 1995). No exogenous carbon source is required because the roots supply nutrients (amino acids, carbohydrates, and organic acids)(Anderson et al 1993: Aprill et al 1990). They could potentially provide cofactors for the activation of bacterial enzymes involved in the pollutant breakdown process (Lugtenberg et al 1997).

When compared to non-root-colonizing bacteria, root-colonizing bacteria genetically designed to digest contaminants should preserve their competitive advantage in the rhizosphere. Furthermore, by integrating biodegradation genes into the bacterial chromosome (Brazil et al 1995), horizontal transmission can be limited; once an area has been remediated, harvesting the plants should remove the specific bacteria's habitat. As a result, rhizoremediation appears to be an attractive, low-cost, low-maintenance in situ treatment for contaminants in surface soils.

The present paper is the review about the details of rhizoremediation. The prime focus of this review paper is to highlight the importance, uses and future aspects of various techniques, advancements and future aspects associated with rhizoremediation technique.

II. RHIZOREMEDIATION:

Rhizoremediation is a mechanism in which soil pollutants are contaminated by microorganisms. Soil contaminants remediated by this process are typical organic compounds which, due to their high hydrophobicity, are not allowed into the plant. The most important method of remediation in this procedure is not usually known to be plants. The plant instead establishes a niche for the destruction of rhizosphere microorganisms. The microorganisms of the rhizosphere are used to produce substrates that enhance microbial life and development when the solar pump drains in water and pollutants. Root exudates and root turnover can be used as substrates for polluting micro-organisms.

A fruitful effort was made to select organizations that could be useful for rhizoremediation. Bacteria that can withstand the contaminant of interest may be enriched by using polluted soil as an initial medium from which to pick. The enrichment will then be inoculated on plants where root colonization selection can be carried out. This process leads to an accommodation plant which supports a rhizosphere pollutant degrader. In this procedure, wild type species have been chosen and, thus, the use of genetically modified microorganisms is not limited.

III. RHIZOREMEDIATION OF CONTAMINATED SOIL:

Rhizoremediation is a subset of phytoremediation that is also known as rhizodegradation, microbe-assisted phytoremediation, or rhizosphere degradation. Pesticides were the subject of the first-ever study for compound degradation using this method. The nature of the pollutants, the soil structure and hydrogeology (the movement of pollutants through soil and groundwater), and the nutritional state and microbial composition of the site are all important parameters for rhizoremediation. It can also be improved by combining compatible plant-microbe pairs. These can be plant- and contaminant-degrading microbes or a combination of plants and PGPR. Many plant species have proven suitable for rhizoremediation, including grasses (e.g., prairie grass) due to their extensive root system, leguminous plants (such as alfalfa) due to their ability to fix nitrogen, and trees such as Salix sp. and Populus sp. due to their perennial growth, high absorption surface areas, and resistance to contaminants. Morus rubra and Betula pendula are also good candidates due to their high biomass production and ability to colonise nutrient-depleted soils efficiently. Furthermore, plant roots aid in the spread of microbes to impermeable layers of soil matrix.

Bacteria, actinomycetes, and fungi, including arbuscular mycorrhizal fungi, are among the microbes that participate in the rhizosphere degradation process (AMF). Root exudates are critical players in the colonisation of rhizospheric bacteria in the root vicinity, which results in the successful degradation of soil pollutants. Organic acids, amino acids, sugars, proteins, alcohols, nucleotides, flavanones, enzymes, and phenolic compounds are found in root exudates. Bacteria in the rhizosphere of plants in such contaminated areas use these exudates as a carbon and energy source, synthesising a variety of metabolites. Rhizoremediation has proven to be superior to bioremediation (bioaugmentation and biostimulation) and phytoremediation processes because it employs indigenous rhizospheric microbial communities that are two to four orders of magnitude greater than bulk soil. When ryegrass and PGPR were used to treat pollutants such as total petroleum hydrocarbons (TPH), degradation rates of up to 65 percent to 90 percent were observed when compared to bioremediation and phytoremediation methods.

The co-evolutionary process between plants and rhizospheric microbes is the key factor on which the rhizoremediation process is based, and thus enhanced reclamation process could be achieved by using suitable plant cultivars in conjunction with suitable rhizobacteria. The degradation process is also affected by soil characteristics such as pH, temperature, light, humidity, and carbon content. It has been discovered that the rate of contaminant degradation by bacteria is slower in acidic soils than in alkaline or neutral soils. In this way, the plant-microbe relationship naturally attenuates, immobilises, or removes these compounds from the soil, restoring its quality and productivity.

3.1 Heavy Metal Contamination:

Hazardous heavy metal pollution in soils is a major source of worry, posing a substantial threat to a variety of environmental niches, including soil ecosystems. Heavy metal contamination is a global concern due to its long-term residence in soil, non-biodegradable nature, and accumulation at various trophic levels of the food web. Heavy metals in soil are a natural occurrence, but their concentration has risen to an alarming level that is damaging to plants and human health as a result of fast industrialization, agronomic practises, and anthropogenic activities.

Smelting, mining, pesticide and fertiliser use, medical wastes, coal combustion, leaded gasoline, sewage sludge, and municipal wastes are all major contributors of heavy metal contamination (Zhang et al. 2010). Some common heavy metals found in polluted soils include aluminium (Al), barium (Ba), arsenic (As), cadmium (Cd), chromium (Cr), cadmium (Cd), copper (Cu), cobalt (Co), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), lithium (Li), and zinc (Zn) (Karthik et al. 2017). Microbes can minimise metal toxicity in three different ways:

1. Microbes convert metals from a harmful to a harmless state.
2. Microbes increase metal bioavailability, which improves metal uptake.
3. Microbes also fix metals in the rhizosphere, preventing plants from absorbing them.

The use of rhizospheric bacteria to clean up heavy metal-contaminated soil has lately emerged as a viable option, and the rhizobial microbes' input is non-toxic (Ullah et al. 2015). The majority of the rhizomicrobial population, which aids in the removal of heavy metals from the soil, is made up of Actinobacteria, Proteobacteria, and Firmicutes (Pires et al. 2017). In such contaminated locations, Ascomycotina and Basidiomycotina fungi, as well as a large number of AMF, have been discovered. Although some plants are hyperaccumulators of particular heavy metals and so aid in the remediation process (phytoremediation), the presence of rhizospheric bacteria aids in the aforementioned process and promotes their growth in stressed conditions. By converting hazardous Cr (VI) to non-toxic Cr (III) after inoculation with Cellulosimicrobium cellulans, Cr (VI) uptake in metal-contaminated soil was reduced by 37% in shoots and 56% in roots of green chilli plants (Chatterjee et al. 2009). Microbacterium sp. CE3R2, Microbacterium sp. NE1R5, Curtobacterium sp. NM1R1, and Microbacterium sp.166 NM3E9 are reported to be potent candidates in agroecosystem remediation of As(V), Pb(II), Cu(II), and Zn(II) (Romano et al. 2017). These bacteria are resistant to the harmful effects of heavy metal poisoning and improve heavy metal bioavailability and solubility. Rhizospheric bacteria clean up the environment by a variety of methods, including chelation, acidification, redox reactions, precipitation, and complexation (Mishra et al. 2017).

Siderophore is an iron chelating chemical that is formed when there is a metal deficit near the rhizosphere. Iron (Fe) is a vital element for plant growth, and its deficiency causes symptoms like chlorosis and hinders chloroplast development and chlorophyll manufacturing in plants grown in heavy metal-contaminated soil. Insoluble iron ($Fe3+$) is converted to soluble iron ($Fe2+$) by these bacteria. Pseudomonas fluorescens produced a siderophore that improved Fe uptake in mung bean and maize plants. Siderophore sequestration is not restricted to Fe; it has also been found to form complexes with other heavy metals such as Cd, Mn, Pb, Zn, and Al [Table 1]. Several rhizospheric bacteria produce exopolysaccharides (EPS), which aid in the sequestration of metal ions and form a sheath to protect them and plant roots from metal toxicity (Mishra et al. 2017). Bacteria that produce EPS include Pseudomonas sp., Arthrobacter sp., Azotobacter sp., and Rhizobia sp.

Table 1: Microbial specific contamination

Plant	Microbe	Contaminant
Brassicajuncea	*Sinorhizobium*sp.Pb002	Lead
Glycinemax	*Glomusetunicatumor G.macrocarpum*	Manganese
Sedumalfredii	*Burkholderiacepacia*	Cadmium,zinc
Orychophragmusviolaceus	*Flavobacterium*sp.	Zinc
Prosopisjuliflora	*Rhizobium*strain	Flyash
*Vignaradiata*seedlings	*Enterobacterasburaie*	Cadmium
Dendrocalamusstrictus	*Aspergillustubingenesis*	Flyash
*Triticumaestivum*L.	*Bacillus*sp.	Copper
Cicerarietinum	*Mesorhizobium*	Chromium
Oryzasativa L.	*Brevundimonasdiminuta*	Arsenic

3.2 Contamination with Polyaromatic Hydrocarbons

Polyaromatic hydrocarbons (PAHs) are a type of organic pollutant that is both dangerous and common. These are extensively spread and result from the incomplete combustion of organic products such as oil, coal, or wood, as well as some waste materials. They have a solubility range of g/kg to 300 g/kg (Kanaly and Harayama 2010). They are divided into two categories based on their molecular structure: low molecular weight (LMW) and high molecular weight (HMW) (HMW). LMWs are PAHs with two or three aromatic rings in their molecular structure, while HMWs are PAHs with four or more aromatic rings. PAH solubility reduces as molecular mass increases. PAHs have the potential to be carcinogenic, mutagenic, and teratogenic in nature, causing irreversible changes in living things that can be lethal if swallowed. According to the United States Environmental Protection Agency (USEPA), 16 PAH compounds have been identified as priority pollutants, including naphthalene, acenaphthalene, acenaphthylene, phenanthrene, fluorene, anthracene, chrysene, pyrene, fluoranthene. (Yan et al. 2004).

PAH is released into the environment as a result of both natural and manmade activities. Forest fires and volcanic eruptions are examples of natural phenomena, while anthropogenic activity include car emissions, petroleum industry leakage, combustion of organic compounds such as wood and other fossil fuels, coal tar manufacture, and so on. PAHs have become a global problem as a result of their harmful qualities, necessitating the development of an effective remediation method. Rhizoremediation has emerged as a promising technique for reclaiming damaged soils from such chemicals (Cook and Hesterberg 2013).

Plants and the microbial community play an important role in the breakdown of xenobiotic chemicals found in soil. A larger bacterial gradient was detected around the root of ryegrass for the breakdown of phenanthrene (up to 86 percent in the 0–3 mm layer from root) in vegetative soil compared to non-vegetative soil (Daane et al. 2001), for example. The root-colonizing microorganisms degrade PAH chemicals by mineralizing them into matching diols and organic acids, which are produced by dioxygenase enzyme breakage of the aromatic ring structure.

3.3 Pesticide contamination

Insecticides, herbicides, and fungicides are examples of pesticides, which are compounds or groups of substances used to control pests (Hernandez et al. 2013). Their main sources are agricultural practises and industries that produce them, which pollute the soil, water, and air. According to accounts, only around 5% of these substances reach the intended species, with the rest accumulating in the soil. According to the Stockholm Convention on Persistent Organic Pollutants (POPs), organic pesticides make up 9 of the 12 organic compounds that persist in the environment. Organochlorine, organophosphate, organometallic, pyrethroids, and carbamates are a few of them (Gilden et al.2010). According to FAO (2017) data, pesticide usage has increased at an annual rate of roughly 11%, rising from 0.2 million tonnes in the 1950s to 5 million tonnes in 2000. Pollution from such persistent substances has serious consequences for all living things, including plants, microbial organisms, and humans.

Pesticides are absorbed in soil and form soil colloids as a result of compartmentalization, which does not change the structure of the soil. The deposited harmful chemicals eventually make their way into the food chain via bioaccumulation in plants, causing major health issues in people that may be carcinogenic in nature (Jayarajet al. 2017). As a result, the discharge of such toxic substances is one of the primary environmental challenges that must be addressed as soon as possible, prompting the development of environmentally friendly reclamation methods such as rhizoremediation.

Pseudomonas, Bacillus, Burkholderia, Alcaligenes, Acinetobacter, Serratia, Streptococcus, Stenotrophomonas, Rhizobium, and fungus such as whiterot (basidiomycetes), mycorrhizae, Phanerochaete chrysosporium, and Ganoderma australe are some frequent examples of microbial species that participate in pest Using the rhizoremediation technique in pea (Pisum sativum) and its endophytic bacteria that accelerated its breakdown, 2,4-dichlorophenoxyacetic (2,4-D) was successfully degraded (Germaine et al. 2006). For chlorpyrifos, cypermethrin, and fenvalerate, the related bacteria were identified as Stenotrophomonas maltophilia MHF ENV20, S. maltophilia MHFENV 22, and Sphingobacterium thalpophilum MHF ENV23, respectively. In the rhizosphere of Pennisetum pedicellatum, S. maltophiliaMHFENV 22 alone is capable of decomposing cypermethrin up to 58 percent in 192 hours at a concentration of 100 mg kg1 (Dubey and Fulekar 2012).

3.4 Petroleum Contaminated Soil

Petroleum and petroleum products are utilised for a variety of applications, and their use has grown exponentially as technology has advanced. Because of the contamination of soil and water, this growth in the usage of petroleum and petroleum-related substances is a major source of worry (Banks et al., 2003). Petroleum contaminants can be removed physically (by plugging holes in the ground, removing the top layer of soil, and using substances to breakdown contamination, for example) or through phytoremediation and rhizoremediation.

When compared to mechanical approaches, phytoremediation and rhizoremediation are both cost-effective and environmentally beneficial. Microbes in the soil and plant root exudates play a significant role in the breakdown of pollutants (Gerhardt et al., 2009). Tang et al. (2010) discovered that bioaugmentation using bacteria, including PGPR, improved total petroleum hydrocarbon rhizoremediation (TPH). As Tang et al. (2010) discovered with Festuca arundinacea, the rate of pollutant degradation varies depending on the plant.

Plants play a modest part in the rhizoremediation of organic chemicals, according to Gao et al. (2011); however, the rhizoremediation process is improved when bacteria are involved (Favas et al., 2014). Plant root exudates have an impact on the microbial community's population.

3.5 Other pollutants

Aside from the aforementioned chemicals, there are a variety of additional contaminants that cause soil contamination and have negative impacts on soil quality and production. Chlorophenols, dibenzofurans, dioxins, and polychlorinatedbiphenyls (PCBs) are some of the most potent carcinogens in nature, having stubborn and bioaccumulative qualities (Godheja et al. 2016). These contaminants are classified as persistent organic pollutants (POPs).

They enter the ecosystem in the same way as other contaminants, have a refractory structure that allows them to stay in the soil for long periods of time and bioaccumulate in the food chain, creating negative environmental impacts. Plants and their associated rhizobacteria, as well as ectomycorrhizal fungi, have been reported to help in the cleanup of such POPs (Afzal et al.2014).

Rhizospheric microorganisms degrade PCBs and dioxins through two basic mechanisms: I anaerobic reductivedechlorination and (ii) aerobic oxidative degradation of the biphenyl ring. In anaerobic environments such as rivers, sediments, and paddy fields, anaerobicreductive dechlorination occurs. Halorespiring bacteria (e.g., Dehalococcoides) substitute chlorine at ortho and meta locations with hydrogen atoms in this process, and the result is transformed to a less harmful form that is further destroyed by aerobic microbes.

Another environmental problem is the potential toxicity of azo dyes in soils, which necessitates degradation and reclamation because their persistence produces various mutagenic effects in living beings (Khandare and Govindwar 2015). In a study conducted by Sinha et al. (2019), a PGPR strain Klebsiella sp. VITAJ23 was found to breakdown a reactive green dye by up to 79 percent and boost plant development of Alternanthera philoxeroides, indicating that such contaminated soil can be mitigated and restored.

IV. CONCLUSION AND FUTURE ASPECTS

Rhizoremediation is clearly one of the most promising approaches for the eco-restoration of contaminated sites, although further study and larger-scale trials are needed. It is also necessary. It has been designed to avoid any inconsistencies in performance during field applications. It has become an unavoidable requirement to think about future possibilities, elucidate mechanisms, and so on using cutting-edge omic technology to study metabolites, pathways, and genes Recent developments in Biotechnology has improved our understanding of effective remediation of such problems. Pollutants are released into the environment through a variety of methods including plants and bacteria (Malla et al.).2018).

Metabolomics, transcriptomics, proteomics, and genomics can all be utilised to gain a better understanding of the biochemical and molecular features of agroecosystems, leading to more reliable technology. These methods can aid in the discovery of novel metabolites and pathways involved in pollution degradation via plant-microbe interactions. These tools will also provide more information on the structural and functional elements of the microbial population, as well as forecast their relationships with diverse ecological processes (Aguiar-Pulido et al. 2016).

Next-generation sequencing (NGS) is another technology that could be used to reduce pollutants by boosting the effectiveness of bioremediation processes by piecing out desirable microbial profiles and other essential information from databases in the form of short reads. Gene editing is carried out through this high-throughput approach, which is both cost-effective and precise (Lowder et al. 2015). In this regard, CRISPR-CAS9 genome editing is one example (Arora et al. 2018).

Another technology known as nanoremediation has emerged, in which nanoparticles are combined with microbial cells to improve the efficiency of the remediation process at areas with high metal concentrations. In addition, well-designed and large-scale field trials are needed to assess the feasibility of new approaches and methodologies (Etesami 2018). Last but not least, communication channels and dialogues should be developed to allow consumers, researchers, industrial sectors, and other relevant authorities to discuss the value of these organic approaches (Prasad et al. 2017).

In the preceding sections, we covered a green technology, rhizoremediation, and how it has proven to be a better technique of soil management than traditional remediation approaches. Various contaminants and their rhizoremediation have now been effectively used in order to reduce or eliminate hazardous pollutants, consequently improving soil quality and productivity. However, because nature is home to a vast microbial diversity, there is still much to learn and exploit regarding plant-microbe interactions, which are mainly unknown. Unraveling these interconnections and controlling the efficacy of the rhizoremediation process as a result would aid this sustainable technology in achieving its full potential.

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