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Remediation: A Novel Approach for Reducing Environmental Pollution

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ABSTRACT

Hazardous contaminants persist more and more now, which negatively impacts the world in various ways. Nearly every second species on earth is experiencing the worst problem with their existence as a result of high environmental contamination. While more recent remediation methods have made improvements, conventional methods have not successfully removed dangerous substances from the environment. Hazardous contaminants elimination using the remediation technique (HCER) is a process that uses remineralization to eliminate hazardous contaminants from contaminated soils and groundwater. The process involves removing hazardous constituents from contaminated soil or groundwater through either mechanical or biological means; then replacing these constituents with beneficial elements to restore environmental quality. Remediation technologies are used for both on-site and off-site applications, including landfills, industrial sites, municipal solid waste landfills, construction sites (e.g., roads), mine tailing piles and other areas where contamination exists due to anthropogenic activities such as mining operations, oil spills and landfill leachate seepage. The present study aims to examine and analyze the literature in the area of remediation strategies used to get rid of toxins, mainly from soil and water.

Keywords- Remediation, Environmental contamination, HCER, Remineralization, Landfills.

I. INTRODUCTION

Pollution has been one of the major concerns with regard to environmental issues. Pollutants can be found everywhere, such as air pollution, which comes from factories or automobiles; water pollution, which comes from sewage treatment plants; land pollution, which comes from industrial waste products and pesticides; noise pollution, which comes from construction sites or trains; and electromagnetic radiation (EMR) caused by cell phones or other electronic devices. Many people are concerned about these types of pollutants because they can cause illness if not properly treated. So it becomes a priority concern to address the polluted environment around us using novel techniques. One of them is remediation, which is often used to refer specifically to the removal and/or remediation of contaminants from landfills, but it can also be applied to any situation where contamination is present in a particular location; for example, remediation may be used to remove asbestos from buildings or groundwater contaminated with petroleum products. Remediation can also refer specifically to cleaning up hazardous waste released into the environment (Gang et al., 2021). The term "environmental remediation" describes activities designed to clean up an existing site after it has become polluted (Theerthagiri et al., 2021). In this context, "remediation" refers only to actions taken on-site at a specific location, while "cleanup" refers more generally (and usually more broadly) than just at that site: cleanup refers to not just removing pollution from one place but rather restoring something like its original state. This broader definition is sometimes referred to as "environmental restoration". Environmental restoration may include both on-site cleanup and off-site disposal of waste materials that cannot safely be stored elsewhere (Yaashikaa et al., 2019).

Different methods of remediation for environmental pollution reduction and restoration are

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being developed and implemented. These include the use of bioremediation and biodegradation in waste treatment (e.g., municipal solid waste management). The term "bioremediation" refers to the process by which a biological system or organism removes contaminants from an environment, for example, through natural processes such as the decomposition of organic matter or the metabolization of chemicals (Dubchak & Bondar, 2018; Medfu Tarekegn et al., 2020; Tarekegn & F Zewdu Salilih, 2020). The term "bio-remediation" refers to remediation using biological organisms that have been modified by genetic engineering techniques to be more effective at removing pollutants from their environment. Examples include genetically engineered bacteria that produce enzymes that degrade toxic compounds (Liu et al., 2019) such as PCBs; genetically engineered fungi that secrete enzymes capable of degrading certain pesticides (Fayyad et al., 2020); and genetically engineered microorganisms used in wastewater treatment plants (WWTP) for degradation of nitrogenous wastes such as nitrates and phosphates. In addition, there is increasing interest in using composting techniques for the removal of heavy metals from soils contaminated with these materials (Diep et al., 2018).

These technologies have increased in recent years as more attention is paid to their potential environmental impacts. The principal advantages of these technologies are that they can be used at a wide range of sites with varying degrees of contamination (from very clean to highly contaminated) and that they do not require large amounts of energy or water for operation. Underlying its important role in addressing environmental pollution, remediation could play a prospective role in the reduction of pollution potentially.

II. REVIEW OF LITERATURE

2.1. Remediation and its types: A definition

According to Wang et al. 2004, the remediation of environmental pollution can be divided into two types: active and passive. Active remediation involves the use of physical or chemical agents that are used to remove pollutants from an area. Passive remediation involves the removal of pollutants through natural processes such as weathering, erosion, decomposition, and biodegradation. Many different methods exist for both active and passive remediation; however, they all have one thing in common: they involve some form of interaction between humans and nature (Wang et al., 2004).

2.2. Potential pollutants occur in the environment: An overview

Pesticides are widely used in agriculture and horticulture (Kapeleka et al., 2019; Moorthy, 2018) as well as industrial applications such as pest control in homes, warehouses, food processing plants (Donga & OM Eklo, 2018), etc. These chemicals are usually applied directly on crops or soil (in spray form) or indirectly by spraying water containing these compounds onto growing plants. They can be found naturally occurring in air and water, but most pesticides are synthesized industrially from organic compounds (Singh et al., 2019) obtained from petroleum products (petroleum ethers), coal tar derivatives (ethylene glycols), natural gas condensates (ethane diols) or sulfuric acid solutions.

Carbon monoxide (CO) is an odourless, tasteless gas that is colourless when dissolved in water. The incomplete combustion of fossil fuels such as gasoline, diesel, natural gas, or wood produces it. Carbon monoxide poisoning can lead to death due to respiratory failure if exposure continues for too long. The most common sources of carbon monoxide are motor vehicles, burning charcoal grills in homes, and wood stoves used for cooking or heating.

Lead (Pb) occurs naturally in the environment (JG Dórea, 2019) but also may be released into the air from industrial activities, including mining operations, smelting facilities, and battery manufacturing facilities (Das et al., 2018). Lead has been found in many types of soil throughout the world; however, it tends to concentrate where there are older buildings constructed with lead-based paints or pipes made of lead-containing materials such as brass, copper, or cast iron. Lead can enter drinking water through leaching from old plumbing systems (Levin et al., 2021) made with lead solder or from contaminated soils near these systems, which tend to have higher levels than surrounding areas because they were built on top of deposits containing high levels of soluble minerals like calcium sulfate (gypsum). In addition, some older wells drilled deep underground may contain high concentrations of soluble salts that dissolve easily into groundwater over time resulting in elevated levels at shallow depths near the wellhead, which supply drinking water supplies downstream from the wellhead location(s). Exposure can occur via ingestion during food preparation, consumption, and inhalation while smoking cigarettes. Chronic exposure causes damage to blood cells, causing anaemia agenesis and developing blood disorders like anaemia, bone marrow failure, and leukaemias. These are some of the potential pollutants that may affect both the natural environment and humans in the long term unless addressed with modern pollution abatement techniques such as remediation.

III. VARIOUS REMEDIATION TECHNIQUES

3.1. Phytoremediation

Phytoremediation is an emerging technology that has the potential to remove pollutants from contaminated soils and groundwater (Ekta & NR Modi, 2018). The process involves the use of plants to remove contaminants from soil and groundwater.

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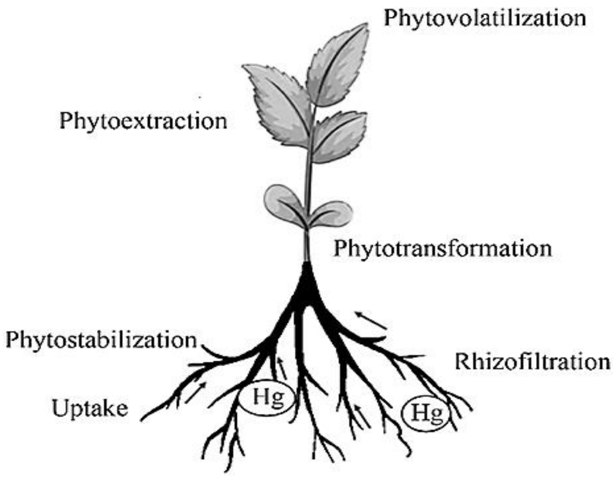

Fig. 1: Phytoremediation using phytoplankton species

The most common plant species used for phytoremediation are grasses, sedges, rushes, and cattails. The roots of these plants can absorb heavy metals such as lead and zinc in contaminated soils (Awa & T Hadibarata, 2020). These metals accumulate in the plant's root system, which can be removed by precipitation or leaching (i.e., water runoff). *Phytoextraction* has been used successfully on sites where heavy metals were present (Pandey et al., 2019), but it has not yet been shown to work as well as phytoremediation on sites contaminated with organic compounds such as pesticides and PCBs (Anerao et al., 2022). The reason for this is unknown but may be due to differences between these two types of contamination (for example, phytoextraction works best on metal-rich soils, whereas phytoremediation works best on organic-rich soils). Another possible explanation could be that there are other factors at play; perhaps some contaminants cannot be removed through phytoextraction because they do not bind strongly enough with plant roots and microorganisms. *Phytostabilization* is a method of using plants to stabilize soil and water and reduce the number of pollutants entering the environment (Cunningham & Berti, 2020). The plants used in this method are called photo stabilizers (Laffray et al., 2021). Phytostabilizer plants are usually grown on farms so they can be harvested after a certain amount of time has passed. Once harvested, these plants will then be able to absorb more nutrients than they would if they were left in the soil alone. *Phytotransformation* is a method to reduce environmental pollution (Ma et al., 2022). The most important part of this process is the removal of toxic compounds from the environment and their transformation into non-toxic compounds, which are harmless to humans and animals. The main types of phytotransformation include biodegradation (the breakdown or decomposition by biological processes), photodegradation (light-induced degradation) and photooxidation (light-induced oxidation) (Bacha et al., 2021). In addition, there are also physical transformations such as thermal degradation (heat-induced breakdown), hydrolysis (breakdown by water) and chemical modification. The *phytovolatation* method is a simple and effective technique for reducing environmental pollution, improving soil quality, and increasing crop yield. It is an efficient method of removing heavy metals from soils or wastewater using plants as bioremediation. The main role of plants in this process is to absorb toxic substances like lead, cadmium, mercury, and other heavy metals through their roots (phytotoxicity) (Limmer & Burken, 2016).

3.2. Bioremediation

Bioremediation is a method of removing contaminants from soil and water (Kumar et al., 2018). It is a very important process that can be used to remove toxins, heavy metals, and other harmful substances from the environment. Bioremediation has been used in many industries, including agriculture, mining, oil and gas production, waste management, and more (S Garg, 2020).

The most common bioremediation techniques are aerobic (oxygen-dependent) or anaerobic (without oxygen). Aerobic bioremediation uses oxygen to break down contaminants, while anaerobic processes use microorganisms without oxygen to degrade pollutants. In both cases, the goal of the process is to convert the contaminant into less harmful compounds that can be removed by natural processes such as erosion or leaching. The main factors affecting this conversion are temperature, pH level, presence of organic matter in the soil or water source, and available nutrients for microbial growth (I Sharma, 2020).

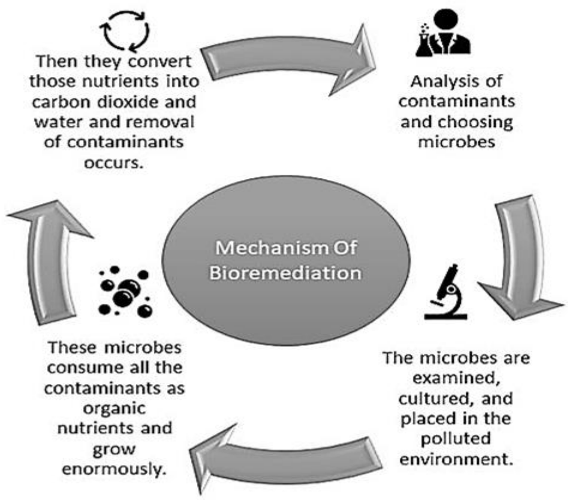

Fig. 2: Mechanism of Bio –remediation

The *natural attenuation* method, the most common form of this technique, is to use a filter, such as activated carbon (Yaman et al., 2021). The concept behind the use of *bioaugmentation* is simple: it involves adding beneficial microorganisms into the contaminated area along with the removal process itself – i.e., removing these harmful substances through biological processes involving microorganisms that are capable of breaking down toxic substances into harmless byproducts which can then be safely removed without any harm being done to humans or animals living around the contaminated area (TC Hazen, 2018). The added beneficial microbes serve two purposes:

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they help break down toxic substances so that they do not remain in place indefinitely but instead get broken down by natural processes over time while at the same time providing a source of food for themselves when possible. The technique can be used in water and air pollution, landfills, wastewater treatment plants, and other areas where there is a high concentration of pollutants. It can also be used for removing toxins from soil, sediment, and groundwater. *Bioaugmentation* has been successfully applied to various types of contaminants, including heavy metals such as lead, mercury, cadmium, arsenic, and chromium (Mawang et al., 2021); organic pollutants like pesticides; synthetic compounds such as polychlorinated biphenyls (PCBs); polyaromatic hydrocarbons (PAHs) and dioxins; persistent organic pollutants (POPs); ionizing radiation such as alpha particles or beta particles; radioactive materials like radon gas (Lourenço et al., 2018); microbiological agents such as bacteria or viruses that are responsible for causing diseases in humans or animals, etc. *Biostimulation* is a form of biological treatment that involves the modification of the environment to stimulate existing bacteria capable of bioremediation (Awari et al., 2020). Bacteria that are capable of bioremediation include, but are not limited to, "Acinetobacter calcoaceticus", "Aeromonas hydrophila", and "Chloroflexus aggregans". Biostimulation is often used in conjunction with other forms of remediation such as adsorption or bioaugmentation. The purpose behind this combination is to provide an additional source for degrading contaminants into less toxic substances so they can be removed from the water supply and soil.

IV. ADVANCEMENT IN MICROBIAL BIOREMEDIATION

Bio-augmentation has evolved as a solution to the issue of the slow and ineffective degradation of toxins and waste by employing genetically engineered microbial strains (Peng et al., 2020; Mishra et al., 2020a, Mishra et al., 2020b). These genetic modifications allow for the genetic manipulation of domesticated plants and animals to have the desired effects (such hybridization, substitution, and induced mutation) (Saxena et al., 2020). In addition to engineering bacteria, there are other more techniques for altering the genetic sequence of a plant, animal, or microorganism, all of which are focused on a particular objective. The terminology "genetically engineered organisms" (GEMs) specifically applies to microorganisms (bacteria, fungi, and yeast, among others) that have undergone in-vitro molecular biology transformations to create genetically modified organisms (GMOs). The insertion of genes causes a single microbe to split into many microorganisms. GEMs may also be used for bioremediation, a procedure that uses microorganisms or their enzymatic systems to break down and remove toxins from the environment (Liu et al., 2019; Jafari et al., 2013). The ability of bacteria to break down environmental toxins is very significant. Bacterial strains that can break down various contaminants, such as nitro-aromatics, chlor-aromatics, and polycyclic aromatic compounds, have been found. These strains will eventually be used to bioremediate contaminated sites. However, due to their chemical inertness and improper decomposition under natural conditions, many bacteria are unable to degrade some of these tenacious and harmful xenobiotic substances, such as heavily nitrated or halogenated aromatic compounds, pesticides, and explosives (Pande et al., 2020).

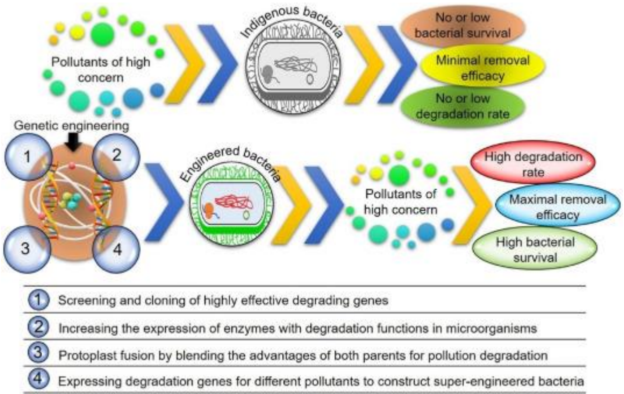

Fig. 3: Induce degradation of pollutants of high concern by genetically engineered microbes. Numbers 1–4 displayed genetic engineering strategies (Liu et al. 2019)

V. REMEDIATION FOR ENVIRONMENTAL POLLUTION REDUCTION: AN INDIAN CONTEXT

The Indian government is using remediation methods to reduce environmental pollution in the country (Sharma, 2020). The Indian government has set up a national program to develop technologies to remediate contaminated land in India. The Ministry of Environment and Forests is implementing the National Programme on Technology Development for Remediation of Contaminated Land, Government of India. It is a public-private partnership between the Centre (Ministry) and State Governments. The main objective behind this program is to develop technology suitable for use in different parts of India, particularly in areas with complex geology and varying topography, as well as locations where there are concerns about land degradation due to climatic changes or salinity intrusion, etc. The program also aims to promote the use of technology for remediation in other countries. As part of their effort, Railways and RDO have designed EcoSan bio-toilets as a sustainable system for handling human excreta using dry composting toilets (NB Mazumdar, 2021). With this composting method, human excreta can be recycled into a resource (as natural fertilizer), which reduces the need for chemical fertilizers. The central pollution control board also issues guidelines for potentially polluted sites for the submission

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of reports on measures they have taken to reduce contaminants in the identified area.

VI. CHALLENGES AND WAY AHEAD

Though remediation is a potentially beneficial method to reduce pollution, not all compounds are subjected to complete and fast degradation. Specifically speaking, Bioremediation methods are also often found to take a long time than other remediation techniques. Being a highly specific process, remediation is costly, and biodegradation may cause the release of more persistent toxic compounds in the environment than the parent compound. Considering the challenges associated, stakeholders shall not rely on any single remediation method to abate pollutant levels in the environment. A multifaceted approach by employing emerging trends and techniques such as sludge drying, fluoridation, and pH correction can be employed.

VII. CONCLUSION

Throughout the world, there is a lot of concern about climate change and its main contributor, i.e., Pollutants in the environment. But still, there are many loopholes in the implementation and discourse of emerging technologies like remediation for environmental pollution reduction. To address this issue, alternative remediation techniques in environmental pollution reduction, as suggested above, must be utilized by adopting best practices with coordinated efforts at a much wider level.

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