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Bacteria and Plants Use in Wastewater Treatment: A Review

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ABSTRACT

There are numerous benefits to treating wastewater using bacteriological and phytochemical methods. Microorganisms are employed in bioremediation to break down or reduce the concentration of harmful substances in polluted environments. In phytoremediation, green plants absorb harmful pollutants and restore abiotic conditions. These methods are often more cost-effective and environmentally friendly compared to conventional approaches. The synergy between plants and microorganisms is effectively utilized in processes like constructed wetlands or wastewater treatment wetlands, which offer several advantages, including low energy requirements, aesthetic appeal, and habitat creation for various wildlife species. However, the combined application of microorganisms and plants in wastewater treatment has not been thoroughly investigated or fully understood. Therefore, this analysis aims to evaluate the roles of microorganisms and plants in wastewater treatment, their interactions, and the conditions that facilitate these processes.

INTRODUCTION

Since water is essential to the survival of all known civilizations, its availability is crucial to humankind. Water is essential to life because without it, nothing can move. Water is the second most essential element needed for all life on Earth, behind oxygen. A 70% portion of agricultural operations rely on groundwater. The primary sources of drinking water and the largest supply for industrial and residential uses are surface and groundwater. An increase in other socioeconomic activities, new technology brought about by industrialization, and population growth all contribute to the direct influx of massive amounts of sewage, which contaminates the environment and natural water bodies.The habitats of wildlife and other living things are harmed by these contaminants. Microbes and wastewater treatment plants are being constructed as essential elements to deal with this possible issue [1,2]. Toxins, such as heavy metals and organic matter that is both compostable and non-composable, have been found in the wastewater by a number of examinations [3-5]. The most economical and ecologically benign technique for decomposing environmental pollutants is called bioremediation, and it makes use of microbes, plants, and their byproducts. As a result, it is the safest technique for treating wastewater [2, 6, 7]. Wastewater may be cleaned of contaminants by bacteria. To lessen or eliminate all toxins from wastewater, certain bacterial strains like *Enterobacter* sp. *and P. australis* are employed. Furthermore, a variety of plants, including *Brassica juncea, Glandularia pulchella, Portulaca grandiflora*, and *Sesuvium portulacastrum*, have the capacity to take in contaminants from their surroundings and incorporate them into their own systems. According to Ali, Abbas [8], the phytosanitary qualities of plants like *Typha latifolia* and *Thelypteris palustris* have proven their efficacy by bioaccumulating heavy metals from animal effluents. It's been discovered that many additional plants work with microbes to support this process. Thus, a novel strategy to enhance pollutant removal from wastewater is the use of particular microbes in conjunction with macrophytes. Partnerships between plants and microbes are one of the best methods for eliminating harmful materials from wastewater. It has been demonstrated that when plants and microbes work together to clean wastewater, toxicity is bound, and water quality is substantially improved [9-11].

Bioremediation

The term "bioremediation" describes a wide range of techniques that employ living microorganisms to either eliminate or render toxic substances in waste materials inert. These bacteria remove the contaminants effectively by oxidizing, immobilizing, or

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changing them into less toxic forms. As a result, it promotes environmental renewal [12,13]. However, for bioremediation to be successful, a few favorable conditions must exist. Furthermore, the application of many biological species, including nematodes, in the degradation of contaminants is encouraged by bioremediation [14]. These organisms bind to and degrade the contaminants in the wastewater during the first cleansing stage. Here, co-metabolism is employed to promote the organisms' quick growth and expedite the healing process [1,15]. In order to remove just the dissolved harmful compounds from industrial wastewater, bioremediation methods include biofilters, bioventing, biosorption, composting, bioaugmentation, bioreactors, and landfill approaches [16,17]. As a result, the organic capacity ratio, microbial concentration, system oxygen content, and temperature all have an impact on cleaning efficiency. The safest and least expensive method of treating wastewater is bioremediation.

Bioremediation of wastewater

It is advised that bioremediation be used as a successful technique to eliminate both liquid and solid pollutants from soil effluents, groundwater, and industrial emissions [18]. Numerous investigations have verified that a variety of microorganisms, including fungus and bacteria that have been grown somewhere else, can be employed to effectively treat wastewater [19]. This makes them more appropriate and economical approaches for treating wastewater with a high foreign matter load as well as for eliminating harmful contaminants from industrial and pharmaceutical wastewater. *Chlorella vulgaris* has been used in the biosorption process, which has been demonstrated to be advantageous for treating textile effluents [20,21]. Various organic substances can be broken down by the multiple strains of bacteria used in the procedure, and they can also absorb nutrients for greater activity and quick growth. The rate of nutrient cycling increases with microbial population and productivity [22].

Microbes' use in bioremediation

Several microorganisms have been reported to have a bioremediation effect. Abioye, Oyewole [23] reported that some species of *Bacillus, Aspergillus* and *Penicillium* sp. play a crucial role in the removal of wastewater contaminants. Especially in industrial wastewater, B. megaterium has the greatest ability to remove heavy metals such as zinc. Likewise, *Basillus subtilis* removed (2130.04 mg/L) Pb in industrial effluents. *A. niger* showed the most positive ability to eliminate Cr to the lowest level, *Penicillium* sp. Other heavy metals eliminated through the action of microbes include; chromium, zinc, cadmium, lead, copper and cobalt [24]. These species are known for their potential for biodegradation and biosorption of industrial effluents. Other microbes known to be involved in wastewater treatment are: *Flavobacterium* and *Zooglea* sp. [25].

Pseudomonas, Acinetobacter and *Enterobacteriaceae* are the dominant bacteria in municipal wastewater [26]. It has been observed that this bacterial group participates in the bioremediation of municipal wastewater Alteromonas species can be used for pollution remediation in paper and pulp mills as it is osmophilic and alkaline resistant. *Micrococcus* sp. is another bacterium that has been shown to be effective at breaking down heavy metals [27]. *Bacillus licheniformis* has been used to treat slaughterhouse effluent. The result showed a large reduction in some of the tested effluent parameters to an average reduction of 95 percent (COD), 95 percent (BOD5), 77 percent (TOC) and 71% (TDS) compared to the raw effluent.

Challenge of bioremediation

The long period of time for remediation of contaminated environment by various bioremediation methods calls into question the practicability of the method. Therefore, the inability of certain compounds to resist biodegradation and bacterial selectivity at specific sites limits the effectiveness of various bioremediation methods [28]. The diversity of biodegradable systems is attributed to microbes, pollution types, energy metabolism and the availability of specific nutrients. This diversity requires ground drilling, civil works and the configuration of a unique site layout to increase the rate of biodegradation and save time on contaminant cleanup. However, since the process often occurs underwater and in remote areas, its impact on local microflora is uncertain. In addition, the use of specific bacterial species makes the method dubious.

Another obstacle is that the dose of pollutants in the wastewater, which determines the speed of the cleaning process [29]. Thus, the need to expand the techniques to industrial scale for rapid performance in huge storage tanks that will prevent slow digestion ratio, membrane fouling, and difficulty in maintaining favorable conditions due to increased surface area for biological activity [30]. Meanwhile, the is a rising interest in developing this technology to the use of phyto – and bioremediation simultaneously will increase the rate of contaminant degradation. This synergy can increase bioavailability for rapid breakdown of contaminants in the wastewater [31]. Other challenges that can affect the feasibility of the process are long start-up time, leaching of particles deep down due to accumulation of microbes. Regulating microbial cell diameter is also challenging. Liquid distributors for fluidized bed processes are expensive for large scale reactors and lead to clogging and fluidized bed uniformity problems [32-35].

Factors affecting microbial remediation of wastewater

An increase in temperature within the acceptable range has a positive effect on the rate at which pollutants are broken down by microorganisms in wastewater. It increased bacterial activity and cellular mechanism and accelerated bioremediation. Because of anionic structures that allow bacteria to bind to metal captions, microorganisms retained cationic charges on their cellular bodies [36,37]. Bioremediation factors include energy sources (electron donors), electron acceptors, temperature, inhibitory substrates or metabolites and pH. It is a well-established fact that bioactivity affects the rate of bioremediation.

The optimization of biodegradation results from the increase in bioactivity. There are several prerequisites for effective microbial remediation. The target substance should primarily be usable by microorganisms and free from inhibitors of microbial degradation. Other factors affecting bioremediation include the disadvantages of prolonged remediation, the challenge of establishing microbial growth under extreme conditions, and the need for contaminant-carrying bacterial diversity [38].

Phytoremediation

Phytoremediation relies on the use of plant parts and products to sequester pollutants from the environment. Using plants to mineralize pollutants is a cutting-edge technique that can take up contaminants by adsorbing them to the plant's radicals in a process called rhizofiltration. The phyto-extracted pollutants are converted into less hazardous substances by the plant enzymes before they are released into the environment [4]. The effectiveness of phytosanitation of a plant depends on its bioaccumulation capacity and the potential of different plant species. For example, *Typha latifolia* and *Thelypteris palustris* have been shown to bioaccumulate heavy metals from animal effluent [2,39]. Many more plants have been found to offer a rapid ability to take up other compounds from wastewater environment [40].

Phytoremediation of wastewater

Phytoremediation is effective for removing toxic substances as it can bind various effluents including heavy metals in wastewater [41]. Phytoremediation of wastewater has negative impacts on various plant species. Suitable plants and their phytoextraction strength are considered important for a successful remediation process. Therefore, wet plants, emerging fauna, aquatic leaf fauna, and submerged plant species are often used to sequester pollutants in wastewater. Other plant species frequently used for phytoremediation include sweet flag [42], cattail and sweet grass [43], canna species [44], *Amaranthus caudatus* L. and *Tagetes patula* L. [45], water hyacinth [46], *Typha latifolia* and *Thelypteris palustris* [47], Duckweed [48] and Cyperus *alternifolius* [49]. In addition, the economic importance, potency and the cost of the plant species are considered in selection of a suitable plant for the process.

Therefore, wet plants, emerging fauna, aquatic leaf fauna, and submerged plant species are often used to sequester pollutants in wastewater. Other plant species frequently used for phytoremediation include sweet flag, Cattail, Canna, Scutellaria, Water Hyacinth, *Typha latifolia* and *Thelypteris palustris*, Duckweed and *Cyperus alternifolius*. In addition, the economic importance, potency and the cost of the plant species are considered in selection of a suitable plant for the process. Canna is reported to have better results than other plants in terms of dissolved oxygen (DO) content, hydraulic efficiency and level of nutrient elimination. Moreover, in canna, calamus, and hybrid canna-calamus systems, degradation level of CODMn, TN, and TP, are increased [50, 51].

Plants use in phytoremediation

Studies revealed the potential of plants in removing water pollutants, but most researchers focused on treating surface and domestic wastewater. Recently, researchers have documented underwater treatments using phytoextraction plants for wastewater remediation.In order to substantiate this fact, there are indications in literatures on how these systems can be used for biological wastewater treatment. Other scientific literature discusses the successful use of plants for pollutant remediation at several sites. Plants such as *Eichornia crassipes* have been tested to improve water purity and remove water particles. Mustafa and Hayder [52] has confirmed hyacinth removal of water particles while *Myriophyllum spicatum* has been confirmed through various experiments.

Gramineae species can biodegrade heavy metals, and microalgae-based methods are effective in nutrient removal, such as: B. simultaneous removal of nitrogen and phosphorus, the synthesis of oxygen and the purification of CO_2. Gramineae, Pontederiaceae, Ceratophyllaceae, Typhaceae and Haloragaceae also have the potential of removing heavy metals from wastewater. Platensis is effective in purifying fish water and serves as a phytoremediation capacity for *L. stolonifera* due to its beneficial ability to break down effluent with biomagnifying heavy metals [51]. For phytoremediation to be successful, factors such as contamination tolerance, resilience to environmental influences, etc. must be considered. High productivity. Plants such as legumes, grasses and trees have been shown to be tolerant to hydrocarbons and pollutants [53].

Plants selection for phytoremediation

A few factors need to be taken into account while choosing plants for a successful phytoremediation. High biomass production is the most crucial selection factor because it will result in high quantities of metal ion elimination [54]. Additional factors include the depth of the root zone and its root characteristics, the levels of tolerance for the particular metal present at the site, the medium's properties (pH, chelators, fertilisers, water logging tolerance, agronomically enhanced phytoremediation), and the addition of chelating agents [55]. It is crucial to understand these factors well in order to improve the plant's overall performance.

Recent strategies for bioremediation

Emerging technology has developed a new bioremediation technique that takes into account specific genetically engineered microorganisms and their impact on a target contaminant [26]. The creation of genetically modified microorganisms (GMM) is a difficult process. Researchers have studied how advanced organisms can break down petroleum hydrocarbons. The first step in creating a GMM is to select the best gene or genes. Then the DNA fragment is inserted into a vector. In host cells containing recombinant DNA, multiple gene copies are sensitized. The final step is to select clones with appropriate DNA inserts and biological traits. Various microorganisms are used as bioremediation agents and are capable of altering toxic species. These microbes are essential for breaking down heavy metals [56]. However, the potential of these plant species has been confirmed. its potential cannot be fully exploited. There is a need to expand research on plant remediation capacity for more complex effluents such as radioactive materials, nanoparticles, etc. By analyzing the synergistic action of plants and microbes, water can be filtered from excess salt and other pollutants in heavy water bodies [57].

Plants-microbes partnership

So far, there is no sufficient study on the synergistic effect of plants and microbes in removing waste contaminants [58]. Little is known about the synergistic effect between plant bacteria in wastewater treatment. However, another study has demonstrated the effectiveness of the combined action of the two in treating winery effluent, achieving over 90 percent nitrogen purification and over 50 percent phosphate removal. Bacteria and algae remove wastewater contaminants better than any known synergy between plants and microbes. Interestingly, they also benefit from synergistic growth advantages [59]. In their work, Khan, Bhardwaj [60] and Kabra, Khandare [61] developed a consortium reactor that efficiently removes dyes and many water parameters in industrial textile contaminants. It is known that the roots of plants support the growth of bacteria and promote the positive elimination of biomagnifying elements that are not degradable from groundwater.

Rhizoremediation is another interactive relationship between plants and microbes for wastewater decontamination. In this mechanism, plant root-related bacteria have been used to purify oil-based wastewater [62]. They claimed that the mutual relationships are based on the bacteria's ability to increase bioavailability and breakdown of organic pollutants, while the plants provide nutrients and protection to the bacteria. The synergistic combination of plants and bacteria has been shown to be effective in improving water quality and reducing algal toxicity in wastewater treatment; It is a complex mechanism in which the microbe-plant synergy breaks down the organic and inorganic pollutants, especially the microbes, thus eliminating the toxicity of the effluent.

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At the same time, the plant provides the microbes with their residents, participates in the efficiency of sanitation, and provides oxygen gas to the aerobic bacteria, improving their performance in the treatment processes. The degree of elimination shows that the synergy of plants and microbes reduces COD, TN and TP to a minimum [12,59]. According to Solomou, Germani [63] the following describes how the interaction of plants and animals in the wastewater treatment process functions:

Plants: The plants used in constructed wetlands, often referred to as macrophytes, play a crucial role in wastewater treatment. They help remove contaminants through various mechanisms, including: (a) Uptake: plants absorb nutrients such as nitrogen and phosphorus from the water, reducing their concentrations in the wastewater. (b) Filtration: the roots and rhizomes of plants act as filters, physically trapping suspended solids and organic matter as the wastewater passes through them. (c) Oxygenation: through photosynthesis, plants release oxygen into the water, promoting the growth of aerobic bacteria that break down organic pollutants. (d) Microorganisms: wetland plants create an environment that promotes the growth of beneficial microorganisms, including bacteria, fungi, and algae.

The following microorganisms play a vital role in wastewater treatment by: (a) Breaking down organic matter: they degrade organic pollutants present in wastewater, converting them into simpler, less harmful compounds. (b) Nutrient cycling: they facilitate the cycling of nutrients, such as nitrogen and phosphorus, in the wetland system, reducing their concentrations in the wastewater. (c) Animals such as aquatic insects, worms, and snails, contribute to the overall functioning of constructed wetlands by: stirring the sediments. Animals that burrow in the wetland substrate help in mixing and oxygenating the sediments, promoting the growth of beneficial bacteria and reducing the accumulation of organic matter.
Grazing on algae; some animals feed on algae, helping to control excessive algal growth and maintaining water clarity. Enhancing nutrient cycling: animals contribute to nutrient cycling by consuming organic matter and excreting nutrient-rich waste, which can be further utilized by plants and microorganisms.

Socio-economic analysis of bioremediation

For the purpose of cleaning up contaminated locations, bioremediation is promoted as a socially, economically, and environmentally responsible policy choice. While affluent nations possess a well-organized policy framework for bioremediation, underdeveloped nations lack such framework [64]. Consequently, this calls into question the potential socioeconomic spillover benefits of bioremediation initiatives. Based on current knowledge, it is possible to advocate for bioremediation as a practise and policy. The advantages that bioremediation initiatives can have for the environment have been the focus of recent research. However, in certain instances, a thorough socioeconomic evaluation is available and emphasises the significance of these measures. A Life Cycle Assessment (LCA) of ongoing projects in industrialised nations was conducted by one study group. The bioremediation (eucalyptus) of a brownfield redevelopment was evaluated [65]. Under two scenarios—no action, bioremediation—the primary (vapour intrusion, surface water) and secondary (human health, ecosystems, resources, economic cost) environmental impacts were evaluated [65].

The need for more research in these areas is evident from this succinct assessment of the body of literature on the socioeconomic implications of bioremediation initiatives. Additional research should be done on variables including the expenses and advantages of each bioremediation project. But it's important to recognise and assess the economic value of indirect socioeconomic advantages like CO_2 abatement. The generation of direct and indirect employment as well as the favourable impact on the local population's income are other factors that need to be taken into account [63]. In summary, Bioremediation is a promising social, economic, and environmental policy option for remediating contaminated sites. However, there is a lack of relevant frameworks in developing countries, which undermines the socio-economic effects of bioremediation projects. Recent research on bioremediation has focused on the environmental benefits it can create. A comprehensive socio-economic assessment is present in some cases, highlighting the importance of such interventions.

One research group carried out a Life Cycle Assessment (LCA) of existing projects in developed countries, assessing primary and secondary environmental impacts under two scenarios (no action, phytoremediation). The primary impacts were minor, while the secondary impacts arising from the remediation intervention were more significant. Under the bioremediation scenario, the project resulted in a "benefit" to human health and ecosystems due to carbon storage associated with the trees and subsequent wood products. Witters, Mendelsohn [66] conducted an LCA of a remediation project in the Campine region, Belgium, using energy plants and analyzing parameters such as energy use and production, CO_2 emissions, and abatement. The external benefit of CO_2 abatement ranged between EUR 55 and 50/hectare. Vigil et al. assessed a bioremediation project with Morus alba in Asturias, Spain, focusing on the importance of bioremediation projects and the further use of the plants for other purposes. The project costs may be offset in less than seven years, and heavy metal concentrations in the soil decreased to levels below Chinese national standards. Sheoran and Choudhary conducted an assessment of gold phytomining on a global level, focusing on hardy species that withstand extreme weather conditions [67].

CONCLUSION

Wastewater treatment using microbes is a highly effective and widely used method for purifying water contaminated with various pollutants. One of the key components of microbial wastewater treatment is the activated sludge process. In this process, a mixed population of microorganisms, including bacteria, fungi, and protozoa, is used to break down organic matter. The microorganisms feed on the organic pollutants present in the wastewater, converting them into carbon dioxide, water, and biomass. Moreover, a specialized group of microorganisms called anaerobes break down organic matter in the absence of oxygen, producing biogas (primarily methane and carbon dioxide) as a byproduct. Anaerobic digestion is particularly useful for treating high-strength organic waste streams and generating renewable energy. This involves the use of specific bacteria and other microorganisms that convert nitrogen compounds into nitrogen gas (denitrification) or store it in the form of biomass (assimilation). These are similar to plants scpecies for the phytoremediation process. The synergy between plants and animals can be effectively utilized in wastewater treatment through a process known as constructed wetlands or wastewater treatment wetlands. This natural treatment approach offers several benefits, including low energy requirements, aesthetic appeal, and habitat creation for various wildlife species. However, it's important to note that the design and maintenance of constructed wetlands must be carefully managed to ensure optimal performance and prevent potential issues such as clogging or excessive plant growth.

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