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SHORT REVIEW

Phytoremediation: An Approach for Petrochemical Contaminated Soil of Assam

Jupitora Devi[1], Sanjib Kalita[2*], Priyakshi Kashyap[3] and Krishna Borgohain[4]

[1]Department of Botany, Gauhati University, Guwahati - 781014, Assam, India
[2]Department of Botany, Moridhal College, Dhemaji - 787057, Assam, India; ksanjib45@gmail.com
[3]Department of Botany, Chaiduar College, Gohpur - 784168, Assam, India
[4]Department of Microbiology, Tripura University, Agartala - 799022, Tripura, India

Abstract

The presence of a component, impurity, or other unfavourable element that taints, corrupts, infects, renders unfit, or degrades a material, or natural environment is referred to as environmental contamination. Due to the potential negative effects caused by the chemical discharges, environmental issues have now become crucial factors to consider. Petrochemical wastes are one of the most serious environmental contaminants which comprise a large group of chemicals derived from petroleum and natural gases. The petrochemical pollutants, belonging to the groups such as greenhouse gases, volatile organic compounds, Particulate Matter (PM) with heavy metals, and polycyclic aromatic compounds, act as potential soil contaminants, causing disturbance and harm to the soil ecosystem. Phytoremediation is an emerging and eco-friendly way to mitigate petrochemical contamination of soil. It is an *in situ* technique to purify contaminated soil or water using plants (trees, shrubs, grasses and aquatic plants) and their associated microorganisms. This technique is favourable for tropical countries like India where there is immense growth of plants. Though plants like *Mirabilis jalapa*, Italian ryegrass, sorghum, maize, and alfalfa are used worldwide, in Assam also various plant species are used for remediation purposes in petrochemical-contaminated soil. *Crotalaria pallida, Cyperus brevifolius, Cynodondactylon. Mimosa pudica* etc. are some of the plant species that have been reported to possess the ability to degrade toxic chemicals into non-toxic or less-toxic products with the aid of microbial colonies in the soil. This review is an effort to through some light on the plants of Assam as well as worldwide along with their family in the remediation of petroleum-contaminated soil. Thus, it will be helpful to select appropriate plants for the purpose of phytoremediation.

Keywords: Petrochemical-Contaminated Soil, Plants, Remediation

1. Introduction

Contamination of soils and waters causes major problems for the environment and human health. The presence of a component, impurity, or other unfavourable element that blemishes, corrupts, infects, renders unfit, or degrades a material, or natural environment is referred to as environmental contamination. Plants can be directly or indirectly used to remediate contaminated soil called phytoremediation technology. This cost-effective plant-based technology where inorganic and organic pollutants can be gathered by plants, can also metabolise organic pollutants and promote their microbial breakdown in the root zone[1]. Petrochemical contamination is one of the major problems in developing countries like India. Polycyclic Aromatic Hydrocarbons (PAH) present in petrochemical-contaminated soil are hazardous pollutants and they cause toxic, mutagenic and carcinogenic effects and are known as human skin photosensitizers and mild allergen[2]. Many reports have claimed that the rhizospheric zone has the potential to rapidly degrade petroleum hydrocarbon[3,4]. Phytoremediation technology is one of the best techniques for water and soil pollution due to hydrocarbons because of its

*Author for correspondence

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simple operation and easy maintenance in sites, eco-friendly and economical[5].

The aim of this work is to emphasise plants that have been used for phytoremediation of soil contaminated with petroleum that are being reported from Assam. The online survey was conducted, and the data were obtained from several electronic scientific databases like Google Scholar, PubMed, Web of Science, Scopus, Science Direct etc. and published information from several articles.

2. Mechanisms of Phytoremediation

Plants may phytoremediate or repair contaminated sites in different ways. The kind of pollutant, bioavailability, and soil characteristics affect the efficacy of phytoremediation. The root system plays the primary role in preventing toxicity which is through where pollutants are largely absorbed by plants. The root makes a vast surface area that helps in absorbing and uptaking water and minerals along with non-essential contaminants or pollutants[7] (Figure 1).

2.1 Phytoextraction

This is also called phytoaccumulation, which describes how plant roots take up and move metal pollutants to above-ground parts of the soil. It is commonly used for the remediation of contaminated soils[8]. This method utilizes plants to accumulate, concentrate and precipitate hazardous metals into the above-ground biomass of plants to remove pollutants from the soil. Nowadays, there are metal hyperaccumulator plant species that can take metals out of polluted soils. Hyperaccumulator plants can accumulate 100 times more metal ions as compared to common non-accumulating plant[9]. Nickel, zinc, and copper are the three most preferred metals removed by the plants adopting the phytoextraction process.

The advantages of phytoextraction range from cost effectiveness to permanent removal of contaminants and the amount of waste materials to be disposed of is significantly decreased from the soil (up to 95%)[8].

2.2 Rhizofiltration

Rhizofiltraton is mainly employed to rectify groundwater, surface water and wastewater contaminated with

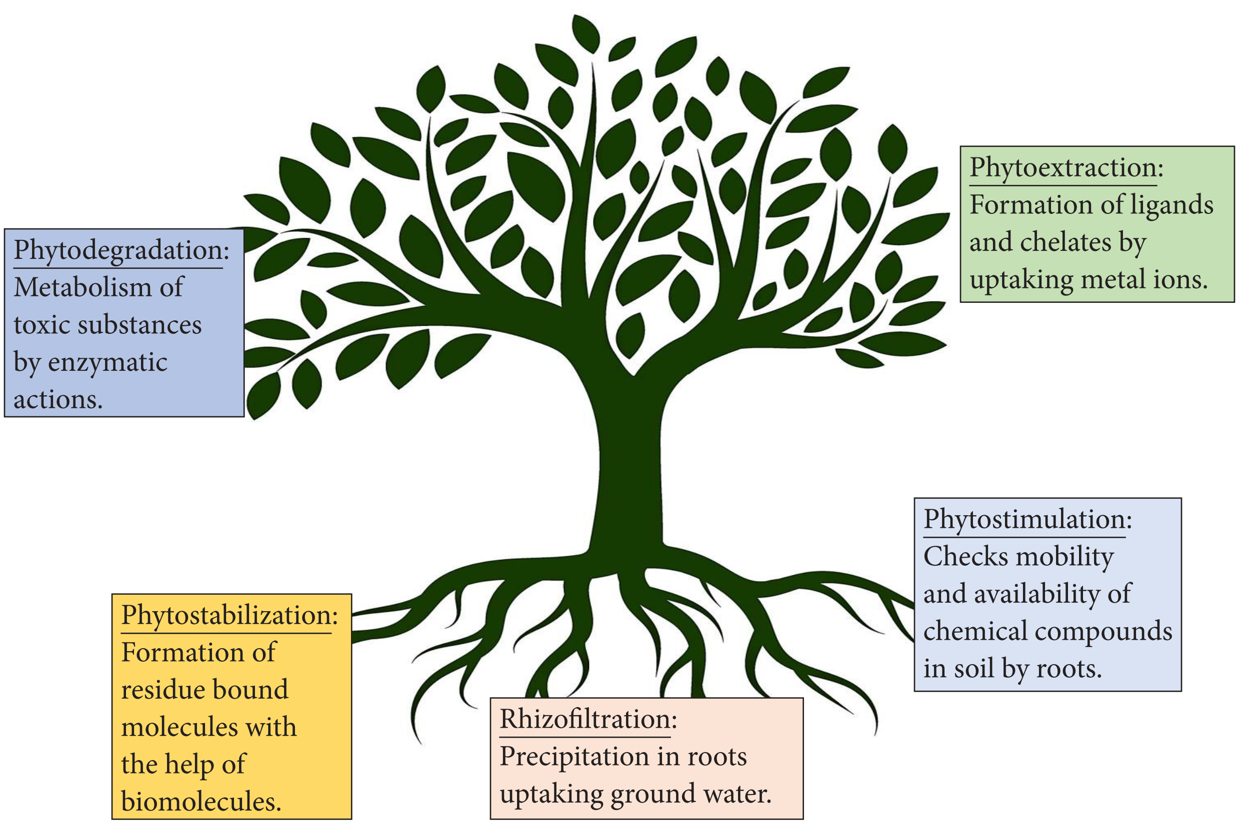

Figure 1. Schematic representation of phytoremediation mechanism.

low concentrations of metals or other inorganic compounds[10]. Pb, Cd, Cu, Ni, Zn, and Cr, which are predominantly retained inside the roots, can be removed via rhizofiltration[8]. It is the adsorption, precipitation, or absorption of pollutants in the root-zone-surrounding fluid. Rhizofiltration differs from phytoextraction in addressing contaminated water rather than soil. Plants can be grown in greenhouses with their roots in water rather than soil. Plants are then planted in the contaminated region once a substantial root system has grown, where the roots absorb both the water and the toxins. The roots are collected as soon as they are fully absorbed contaminant. Studies on the removal of lead from water have focused on sunflower, Indian mustard, tobacco, rye, spinach, and maize. In one study, sunflower significantly lowered lead concentrations after just one hour of treatment[7].

The lead of rhizofiltration is that both terrestrial as well as aquatic plant species can be used. Also, it is not necessary for the pollutants to move from the soil to the shoots. As a result, species besides hyperaccumulators may be employed. Because their roots are lengthier and fibrous, there is more surface area on the roots of terrestrial plants[7] while constant pH adjustments, the necessity of a nursery for plant growth, the requirement for harvesting periodically, the expenditure of the process etc. are some drawbacks and restrictions[8].

2.3 Phytovolatilization

This is the process of using plants to extract pollutants residing in the soil, transform them into volatile states, and let out them into the environment[8]. The pollutants are absorbed into the plant's body; however, they are later transpired with water vapour from leaves as either an inflammable form of the contaminant or as a smaller breakdown volatile product[10]. When a pollutant diffuses from the stems as well as other parts of the plant earlier to reach the leaves, this is often referred to as phytovolatilization[7]. The causes of phytovolatilization can range from pollutants in the soil, sediment, or water. This method has been employed mainly for the removal of mercury from contaminated sites. In addition to this, it has been found to happen with volatile inorganic chemicals like arsenic and selenium, as well as trichloroethene-like volatile organic compounds[10]. The benefit of this method is that the contaminant may be converted into a simpler compound or a less lethal substance. Releasing mercury into the atmosphere, which is then recycled by precipitation and dumped back into lakes and seas, this has the downside of replicating the anaerobic bacteria's production of methylmercury[8].

2.4 Phytostabilization

This is also referred to as existing inactivation. It is typically utilised for sludge, sediment, and soil remediation[8]. It involves using specific plant species to absorb and accumulate toxins in soil and groundwater, adsorb chemicals to roots, or cause precipitation inside the rhizosphere of plants. Through this process, the contaminant's mobility is reduced, migration to the groundwater is prevented, and the metal's bioavailability to the food chain is decreased. This method can also be applied to areas where natural vegetation has failed to thrive because of high concentrations of metal in the soils or physical impairment to the materials' surface. By replanting metal-tolerating plants in the areas that are contaminated, the possibility for pollutant movement by transport of exposed surface soils, wind erosion, and leaching of soil pollution into underground water is minimized. Phytostabilization can happen because of complexation, precipitation, sorption, or metal valence reduction. Chromium (Cr), arsenic (As), lead (Pb), cadmium (Cd), zinc (Zn) and copper (Cu) can all be reduced with it. The process of phytostabilization makes use of the alterations in the soil environment and chemical properties carried on by the existence of the plant. These variations in soil chemical properties could promote the adhesion of pollutants to plant roots or soil, or metals precipitating onto the plant roots. Metals and other mineral impurities in soil and remaining have been effectively dealt with via phytostabilization[10]. Some benefits of this technique include the lack of a need for hazardous material or biomass disposal and its high effectiveness in situations when quick immobilisation is necessary to protect ground as well as surface waterways[11]. Additionally, the occurrence of plants declines soil loss and the amount of water availability in the system[8]. This cleaning technology has several significant disadvantages, ranging from the presence of contaminants in the soil, the need for widespread fertilisation or soil alterations, the requirement for ongoing monitoring, and the possibility that soil amendments were primarily responsible for the stabilisation of the contaminants.

2.5 Phytodegradation

This also referred to as phytotransformation, involves the degradation of complex organic molecules to simple molecules or the amalgamation of these molecules into plant tissues[12]. Contaminants are degraded by plants during phytodegradation once they have been absorbed by the plant. Plant absorption often only happens when the pollutants' hydrophobicity as well as solubility fall within a specific permissible level, just like with phytoextraction and phytovolatilization. It has been shown that phytodegradation can remove some organic pollutants from soil, sediment, or groundwater, including herbicides, chlorinated solvents, and munitions[10].

2.6 Rhizodegradation

It is the cessation of pollutants within the rhizosphere, or root zone, of plants, and is also known as phytostimulation. Bacteria or other microbes, whose populations normally flourish in the rhizosphere, may carry out it. Studies have revealed that rhizospheric soil accommodates 100 times more microorganisms compared to non-rhizospheric soil[8]. As the plant releases amino acids, sugars, enzymes, and other substances these can promote the growth and development of bacteria, hence microorganisms are common in that region. The increased surface area provided by roots allows bacteria to proliferate and serves as a conduit for the transfer of oxygen from the atmosphere. Rhizodegradation is primarily effective in contaminated soil due to its localised nature, and it has been studied and found to have some success in treating a wide range of organic chemicals, including Polycyclic Aromatic Hydrocarbons (PAHs), petroleum hydrocarbons, Polychlorinated Biphenyls (PCBs), chlorinated solvents, pesticides, toluene, xylenes, benzene and ethylbenzene[10]. It can be regarded as plant-assisted bioremediation, which involves releasing exudates and enzymes into the rhizosphere to encourage microbial and fungal breakdown[13].

3. Plants Used for Phytoremediation in Petroleum Hydrocarbon Contamination

The most prevalent category of organic pollutants is petroleum hydrocarbons. Aliphatic compounds, Polycyclic Aromatic Hydrocarbons (PAHs), and volatile monoaromatic substances including toluene, benzene, xylene (BTEX) and ethylbenzene are included under Total Petroleum Hydrocarbons (TPHs). For phytoremediation, both trees and grasses are frequently utilised, with trees being chosen for BTEX cleanup and grasses for PAH and TPH remediaton[14].

Studies revealed that *Mirabilis jalapa* L. is a decorative plant that has a good tolerant ability to the soil contaminated with petroleum[15]. They can grow in soil that is contaminated with petroleum up to upto10,000 mg/kg. When the amount of pollutants in the soil was ≤10,000 mg/kg, the plants could efficiently encourage the degradation of TPHs. As a result, *M. jalapa* is a crucial plant that may be used to efficiently phytoremediation soil that has been contaminated with petroleum to the extent of about 10,000 mg/kg[15] (Table 1).

Table 1. Plants used in phytoremediation worldwide

Sl. No.	Name of the plant	Family	References
1.	*Mirabilis jalapa*	Nyctaginaceae	15
2.	*Brachiaria brizantha*	Poaceae	16
3.	Italian ryegrass, bermudagrass, alfalfa, maize, sorghum, rice, kudzu and beggar ticks	Poaceae, Fabaceae, Asteraceae	17
4.	*Pteris vittate, Imperata cylindrica, Mucuna bracteata* and *Epipremnum aureum*	Pteridaceae, Poaceae, Fabaceae, Araceae	18
5.	*Vetiveria zizanioides* (L.) Nash	Poaceae	19
6.	Alfalfa	Fabaceae	20
7.	*Paspalum vaginatum* Sw.	Poaceae	21

The cDNA sequences classify some of the up-regulated genes found in the roots of *Cynodon dacylon* grown under petroleum hydrocarbon stress into six different groups: general metabolism (including alcohol dehydrogenase, fatty acids ligase, glycosyl transferases, and profilin), signal transduction (including serine/threonine phosphatase, G-protein, and histidin kinases), protein synthesis and degradation (ubiquitin, ribosomal proteins), nuclear transport (including nucleoporin 98 and La-domain protein), unassigned biological activity (e.g. B12D) and sequences without identity[22]. The highest hydrocarbon removal (85%) was observed in spiked soil modified with compost (5% v/v), biochar (5% v/v) and consortia (bacterial strains of *Actinobacter bouvetii*, *Pseudomonas poae*, *P. rhizosphaerae*, and *Stenotrophomonas rhizophila*)[23]. Ryegrass amended compost displayed the maximum TPH removal (68.5%), followed by white clover with biochar (68%) in a study that concluded that adding compost to polluted soil improves the performance of wheat, ryegrass and maize (Family: Poaceae) to remediate TPHs. In addition, it was discovered that biochar was more suited for growing white alfalfa and clover in soil contaminated with crude oil[24]. Investigation revealed that using bacteria and alfalfa plants together to degrade petroleum hydrocarbons is more effective than using just bacteria or plants alone. These bacteria contain 1-aminocyclopropane-1-carboxylate (ACC)-deaminase activity and resistance to contamination from petroleum hydrocarbons[25].

4. Plants Used for Phytoremediation in Assam

In Assam also different plants are used for phytoremediation purposes, some of them are mentioned in Table 2.

Table 2. Plants that are used for phytoremediation in Assam

Sl. No.	Name of the plant	Family	Soil collection site	References
1.	*Cyperus odoratus* and *Cyperus laevigatus*	Cyperaceae	Oil India Limited, Duliajan	26
2.	*Crotalaria pallida*	Fabaceae	Noonmati refinery, Guwahati	27
3.	*Cyperus brevifolius* (Rottb.) Hassk	Cyperaceae	Oil India Limited, Duliajan	28
4.	*Cynodon dactylon* (L.) Pers.	Poaceae	crude oilcontaminated pit of Jorajan, Duliajan	29
5.	*Cyperus brovifollia, Mimosa pudica, Cassia tora, Ageratum conyzoides,* and *Cymbopogon winterianus*	Cyperaceae, Fabaceae, Asteraceae, Poaceae	petroleum contaminated oil field at Lakowa, Sibsagar	30
6.	*Polygonum hydropiper* (L.), *Xanthium strumarium* L., and *Ageratum conyzoides* L.	Polygonaceae, Asteraceae,	The Lakowa oil field	31
7.	*Cyperus brevifolius* (Rottb.) Hassk, *C. rotundus* (Linn.)	Cyperaceae	contaminated soil of Duliajan	32
8.	*Axonopus compressus* (Sw.) P. Beauv.	Poaceae	oil-contaminated site of Oil India Limited, Duliajan	33
9.	*Cyperus rotundus*	Cyperaceae	oil-contaminated field of Duliajan	34
10.	*Colocasia esculenta*	Araceae	vicinity of the Geleky oilfield of Sibsagar	35

Gordonia amicalis, in symbiotic association with *Azadirachta indica,* found to be effective in degrading total petroleum hydrocarbon[36]. TPH concentrations decreased while soil biological activity and nutrient content increased when *P. aeruginosa* N3 as well as *P. aeruginosa* N4 bacteria degrades crude oil, were used. Survivability of native plants like *Tectona grandis, Michelia champaca*, *Gmelina arborea* and *Azadirachta indica* can be uplifted by treating soil contaminated with crude oil along with the bacteria growing in that soil from 51–99 %[37].

An experiment suggested that legume species have tolerance ability towards heavy fuel-oil contaminated soil under study, revealing heavy fuel oil removal efficiency directly proportional to the plant biomass. Thus, three out of the eight plant species under investigation, *Melilotus albus*, *Medicago sativa* and *Lotus corniculatus* were performed to be the most competent among them in heavy fuel removal. Simultaneously, *M. albus* and *L. corniculatus* were found to be efficient in recovering phosphorus and nitrogen-like soil nutrients by showing tolerance towards heavy fuel[38]. Phytoremediation efficiency can be increased with the aid of the addition of certain amendments, which enhances plant growth as well as the uptake of nutrients and water. Because of their increased plant growth rate and overexpression of the genes that control metal uptake and translocation, genetically modified plants have a significant potential for phytoremediation[39]. An affordable and environmentally friendly method is microbial-assisted phytoremediation. By secreting enzymes and chemical irritants that would either directly or indirectly assist the plant, soil microorganisms are able to break down toxins in various ways and resist stress. Thus, microbes have a significant role in phytoremediation and control of biogeochemical processes, especially in rhizomatic practices[40]. The most typical method for improving phytoremediation is to create a synergy between bacteria or fungi that can grow in the rhizosphere and plants, which increases their bioavailability and offers substances that aid in phytoremediation, giving the latter greater resistance and restored conditions for metal extraction[41]. *Bacillus* sp., *Pseudomonas* sp., and *Aspergillus*-like microorganisms and *Zea mays*, *Solanum nigrum* and *Brassica juncea*-like plants have a great ability to remediate an environment contaminated with heavy metals. The process of phytoremediation was greatly enhanced by the addition of metal-tolerant microorganisms and bacteria/fungi that stimulate plant growth. Thus, selecting proper plant species and microorganisms can have a significant impact on the efficacy of phytoremediation[42].

5. Conclusion

Plants growing in petroleum-contaminated soil are found to be of reduced height, root growth as well and biomass. Thus, plant roots covering a larger surface area are beneficial for the accumulation of water and nutrients. Common selection criteria for trees or grasses often include: 1) toxicity resistance, 2) environmental tolerance, 3) high productivity and big biomass production, 4) low bioaccumulation and trophic transfer potential, and 5) adaptability for different soil types. Additionally, interactions between the pollutants, physical characteristics of the soil, microbial population, plants, and the regional climate conditions lead to the breakdown of petroleum hydrocarbons. As a result of the interaction of these factors, plants can remediate the environment which also provides erosion control and, thus, prevents contaminants from surface spreading. By planting plants that accumulate high amounts of TPH, it is possible to rectify soil contamination and ultimately make the land suitable for cultivation. However, these plants may have limited ability in the selection of bioavailable hydrocarbons. Hence, phytoremediation is a green technology in which plants create an environment more favourable for the dissipation of contaminants for the establishment of vegetation[43].

6. References

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