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Review Article

Sustainable soil remediation through green technology

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Soil, mentioned as the Soul of Infinite Life helps in providing anchorage to the plants, serves as the construction medium, holds numerous biotas, purifies water, and turns all the wastes into composts. The increased activities of urbanization, industrialization, and intensive agricultural practices pollute the soil and add up the pollutants in the food web. This scenario affects food production and the supply of healthy food to the people is also affected. To ensure food security and quality food production, soil remediation needs to be ensured. This review discusses the scenario of pollution, green technology approaches, their cleaning mechanism, and strategies in green technologies. The importance of green technology has been emphasized because of its sustainable nature.

Keywords: *soil, remediation, green technology, environment, crops, food security*

Introduction

The volcanic eruptions form different rocks, such as igneous, sedimentary, and metamorphic rocks encompass numerous minerals. Over a while, these rocks undergo different weathering processes, leading to soil formation. This soil consists of mineral matter, organic matter, air, and water, and acts as a natural resource that serves as a medium for plant growth. Industrial pollution, excessive mining, farming, and unregulated waste management lead to the depletion of soil health by causing soil pollution (Xing *et al.*, 2022). Heavy metals like Cr, Zn, Ni, Co, Cd, Cu, Mn, and Pb concentrations are increasing in the soil through industrial wastewater (Sadia et al., 2020). These biosolids are the main contaminants that get mixed in the water reservoirs and groundwater which pertains to water pollution. The annual global production of industrial chemicals has doubled to 2.3 billion tonnes since 2000 and is expected to double again by 2030. The pollution may be invisible to the human eyes but the food we eat, the water we drink, and the air we breathe are all encompassed by different pollutants. To sustain soil fertility and human health, it is high time to start up the remediation with a larger focus. Thus, the technology of sustainable remediation focuses on reducing soil pollution and maximizing the net environmental cleanup. Also, the remediation plays a vital role in conserving biodiversity and maintaining the ecology (Vimal & Gordana, 2022).

Sustainable remediation and green technology

Sustainable Remediation is a concept of balancing the environmental, economic, and societal benefits of remedial actions, which is a broader and holistic remediation approach (Paul and Melissa, 2015). Close monitoring and coordination in reuse planning are the keys to sustainable remediation. The following practices can be adopted for carrying out the remediation plans at the micro level,

- Thermal remediation: Heat is used to remove the soil contaminants
- Bioremediation: Living organisms are used to remove the soil contaminants
- Mycoremediation: Fungi are used to remove the soil contaminants
- Phytoremediation: Plants are used to remove the soil contaminants

Among all, phytoremediation, which is also called 'Green Technology' gained more attention due to its increased sustainable nature. Raising plants in a contaminated environment to remove the toxic elements is called as phytoremediation. The increased plant biomass will lower the total toxic element concentration in the soil (Annie and Gilbert, 2013). Plants have remarkable metabolic systems, absorbing capabilities, and transport mechanisms that help in taking up the contaminants from the soil and then accumulate in the plant body. Some of the pollutant-accumulating plants are,

- *Armeria maritima*
- *Ambrosia artemisiifolia*
- *Brassica juncea*
- *Brassica napus*
- *Brassica oleracea*
- *Ceratophyllum demersum* L.
- *Eichornia crassipes*
- *Festuca ovina*
- *Helianthus annuus*
- *Paspalum conjugatum* L.
- *Populus* spp.
- *Thalspi rotundifolium*
- *Triticum aestivum*
- *Vetiveria zizanioides*
- *Zea mays*

The cleansing mechanism in green technology

A broad range of contaminants like metals, radionuclides, chlorinated solvents, polycyclic aromatic hydrocarbons, pesticides, explosives, and surfactants are absorbed by the plant. Plants have the remarkable ability to metabolize various elements from the soil and accumulate inside its tissues. The toxic elements are taken up by the plants through their roots and translocate to their shoots and leaves which arrests the leaching of contaminants in the soil (Arjun *et al.*, 2022). These plants are carefully removed and disposed of elsewhere in a non-polluting way (USEPA, 2004). It works in the following ways (Clemens *et al.,* 2002),

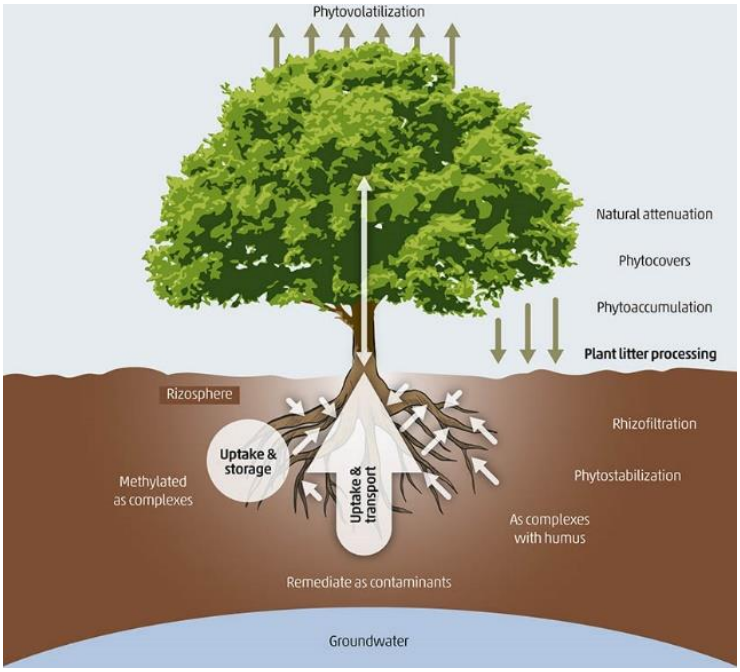
- **Phytoextraction:** The natural ability of the plant to take up certain substances from the environment. The toxic metals get accumulated, absorbed, and translocated at the different parts of cells as vacuoles, cell membranes, cell walls, and a few metabolically inactive parts in plant tissues (Lajayer *et al.*, 2019).
- **Phytodegradation:** Plants convert the organic pollutants into a non-toxic form. The organic pollutants line pesticides are remediated through degradation and transformed by different parts of a plant. The plants absorb the contaminants and they either convert them completely or break them into smaller and less harmful compounds (Garrison *et al.,* 2000).
- **Phytostabilization:** Plants release chemicals that bind the contaminants and make them less bioavailable and immobile in the ecosystem. The remediation is attained by inactivating or immobilizing the toxicants and pollutants present in the rhizosphere. The mobility of the contaminants and their bioavailability gets reduced because of the stabilizing activity of the plant roots which results in the lowered toxic effects. The plants tend to form a bound residue with toxic contaminants, which accumulate in the solid matrix and are unavailable to pollute the soil (Li *et al.,* 2002).
- **Phytovolatalization:** Plants extract the pollutants from the soil and convert them into gases that are harmless when released into the atmosphere. This process takes place step by step, at first the soil contaminants transform the less volatile chemicals into a more volatile form and then it will be released into the atmosphere. Some of the organic contaminants get volatilized to the atmosphere directly from the stems and leaves (Limmer and Burken, 2016).
- **Phytodesalination:** The salt-tolerant plants may extract the excess salts from the soil and helps in improving productivity by the phytodesalination process. The halophytic plants are utilized in carrying out the desalination process (Arif *et al.,* 2020).

The other remediation measures associated to sustainable remediation measures are as follows,

- **Rhizofiltration:** It is similar to phytoextraction but used for the remediation of contaminated groundwater. The toxic substances are removed by the plant roots from the saturated zone for remediating the contaminants through adsorption/concentration/precipitation from the groundwater, surface water, and wastewater. The

aquatic plants are involved in rhizofiltration which helps in absorbing the contaminants and cleaning the surface water resources (Mithembu, 2012).

- **Rhizodegradation:** The breakdown of organic contaminants in soils by fungi and microorganisms associated with the root zone. Microbes at the rhizosphere regions are capable of mineralizing organic compounds like polyaromatic hydrocarbons and polychlorinated biphenyls (Cherian and Oliveria, 2005).
- **Vermiremediation:** Removal of contaminants by earthworms. The chemical tolerant earthworms are used to remediate the contaminated soils (Butt et al., 2004). These earthworms can remove heavy metals, pesticides, lipophilic organic compounds, micropollutants, and polycyclic aromatic hydrocarbons from the soil. This technique is considered as low-cost and convenient technology (Sanjay *et al.*, 2021).



(Source: Vithanage *et al.*, 2011)

Figure 1. Phytoremediation functions of a plant source for remediating arsenic (Ar) contaminated soil

Strategies and approaches to green technology

Various strategies like environment awareness, forestry plantations, integrated nutrient management, litter turnover, manuring, nutrient management for soil organic carbon sequestration, regular organic inputs, residue retentions, soil biological management, urban waste management, and woodlot islets are followed to improve and restore the soil quality by adapting the soil remediation strategy (Aniket *et al.*, 2023; Lal, 2015). The uptake mechanism of toxic elements by the plant is affected by different factors viz., plant species, chelating agent added, bioavailability of the metal, chemical properties of the contaminants, environmental condition, root zone, and properties of the medium. Thus, proper planning and execution of the plan are essential in acclimatizing green technology at the field level

Conclusion

As an important natural resource, the properties of soil vary inch by inch. Involving the local communities in understanding the soils and proposing a soil management plan will help in the proper execution of the remediation measure. Adopting certain waste management practices will help in minimizing the addition of pollutants to the soil. Among the various remediation technologies, the remediation measures through green technology are very sustainable as it is aesthetic, non-intrusive, cost-effective, preventing erosion and leaching. Through collective efforts and further research works the soil resources can be safeguarded and a healthier environment can be handed over to the upcoming generation.

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Author contributions

Both of the authors developed this manuscript and approved the same for publication.

Conflict of interests

The authors declare no conflict of interest.

Ethics approval

Not applicable.

AI tool usage declaration

The authors did not use any AI and related tools to write this manuscript.

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