PHYTOREMEDIATION

Phytoremediation is defined by UNEP as the use of living green plants for *in situ* removal, degradation, and containment of contaminants in soils, surface waters and groundwater.

Phytoremediation is the direct use of living plants for in situ remediation of contaminated soil, sludges, sediments, and ground water through contaminant removal, degradation, or containment. Growing and, in some cases, harvesting plants on a contaminated site as a remediation method is an aesthetically pleasing, solar-energy driven, passive technique that can be used to clean up sites with shallow, low to moderate levels of contamination. This technique can be used along with or, in some cases, in place of mechanical cleanup methods. Phytoremediation can be used to clean up metals, pesticides, solvents, explosives, crude oil, polycyclic aromatic hydrocarbons, and landfill leachates. Phytoremediation has been studied extensively in research and small-scale demonstrations, but fullscale applications are currently limited in number. Further development and research of the mechanisms described below likely will lead to wider acceptance and use of phytoremediation.

Phytoremediation is a general term for several ways in which plants are used to remediate sites by removing pollutants from soil and water. Plants can degrade organic pollutants or contain and stabilize metal contaminants by acting as filters or traps. Some of the methods that are being tested are described below.

Phytoextraction

Phytoextraction, also called phytoaccumulation, refers to the uptake and translocation of metal contaminants in the soil by plant roots into the aboveground portions of the plants. Certain plants called hyperaccumulators absorb unusually large amounts of metals in comparison to other plants. One or a combination of these plants is selected and planted at a site based on the type of metals present and other site conditions. After the plants have been allowed to grow for several weeks or months, they are harvested and either incinerated or

composted to recycle the metals. This procedure may be repeated as necessary to bring soil contaminant levels down to allowable limits. If plants are incinerated, the ash must be disposed of in a hazardous waste landfill, but the volume of ash will be less than 10% of the volume that would be created if the contaminated soil itself were dug up for treatment.

Rhizofiltration

Rhizofiltration is the adsorption or precipitation onto plant roots or absorption into the roots of contaminants that are in solution surrounding the root zone. The plants to be used for cleanup are raised in greenhouses with their roots in water rather than in soil. To acclimate the plants once a large root system has been developed, contaminated water is collected from a waste site and brought to the plants where it is substituted for their water source. The plants are then planted in the contaminated area where the roots take up the water and the contaminants along with it. As the roots become saturated with contaminants, they are harvested and either incinerated or composted to recycle the contaminants.

Phytostabilization

Phytostabilization is the use of certain plant species to immobilize contaminants in the soil and ground water through absorption and accumulation by roots, adsorption onto roots, or precipitation within the root zone. This process reduces the mobility of the contaminant and prevents migration to the ground water or air, and it reduces bioavailability for entry into the food chain. This technique can be used to reestablish a vegetative cover at sites where natural vegetation is lacking due to high metal concentrations in surface soils or physical disturbances to surficial materials. Metal-tolerant species can be used to restore vegetation to the sites, thereby decreasing the potential migration of contamination through wind erosion, transport of exposed surface soils, and leaching of soil contamination to ground water.

Phytodegradation

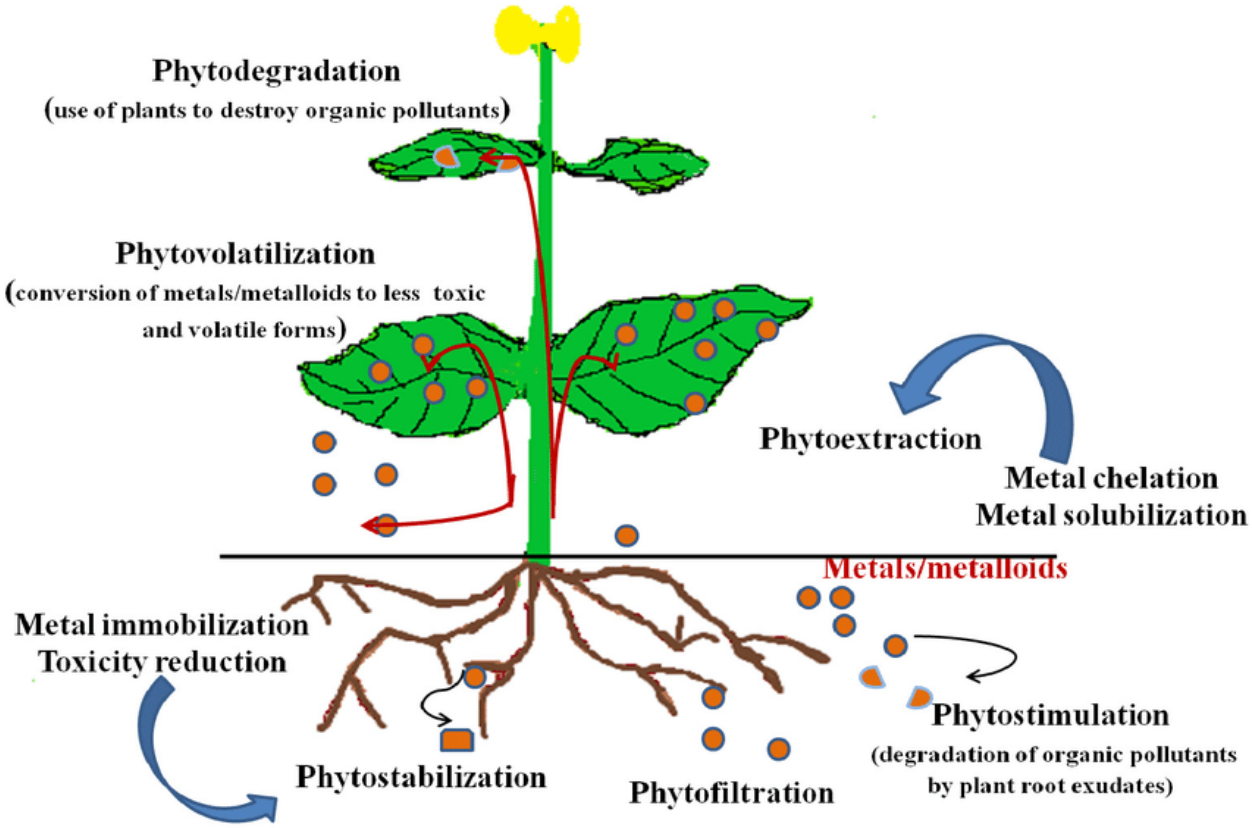
Phytodegradation, also called phytotransformation, is the breakdown of contaminants taken up by plants through metabolic processes within the plant, or the breakdown of contaminants external to the plant through the effect of compounds (such as enzymes) produced by the plants. Pollutants are degraded, incorporated into the plant tissues, and used as nutrients.

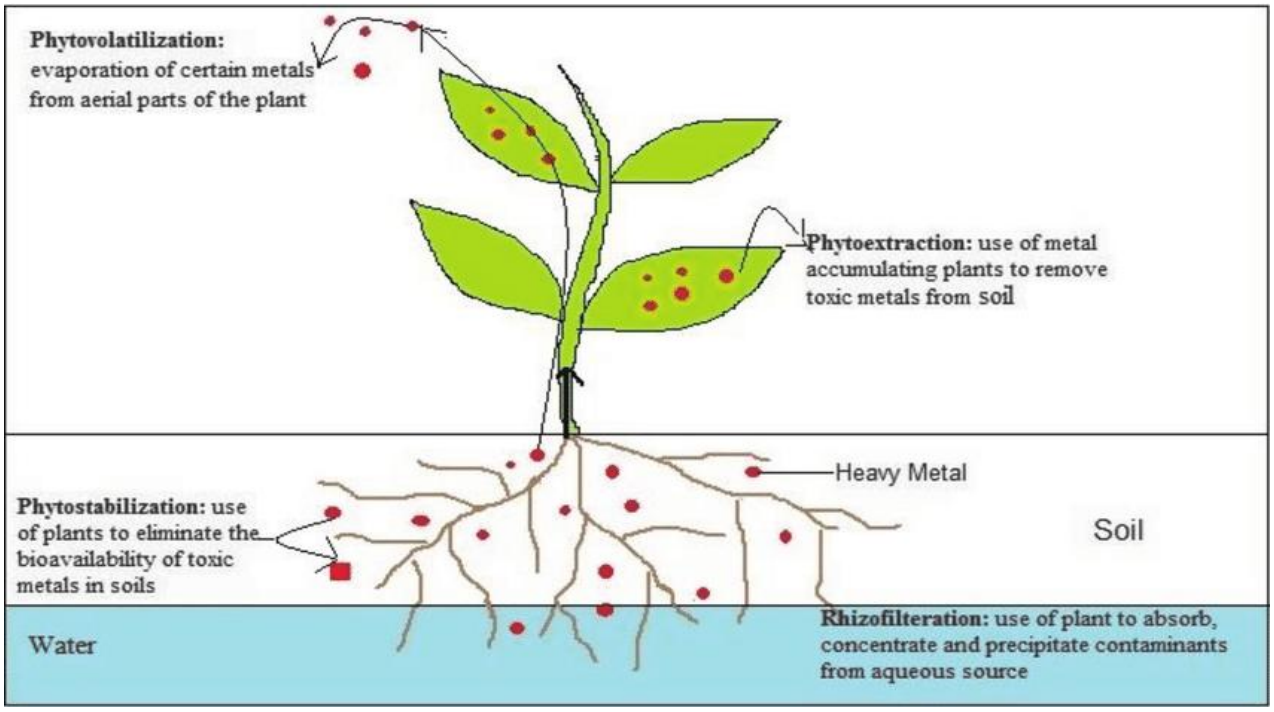
Rhizodegradation

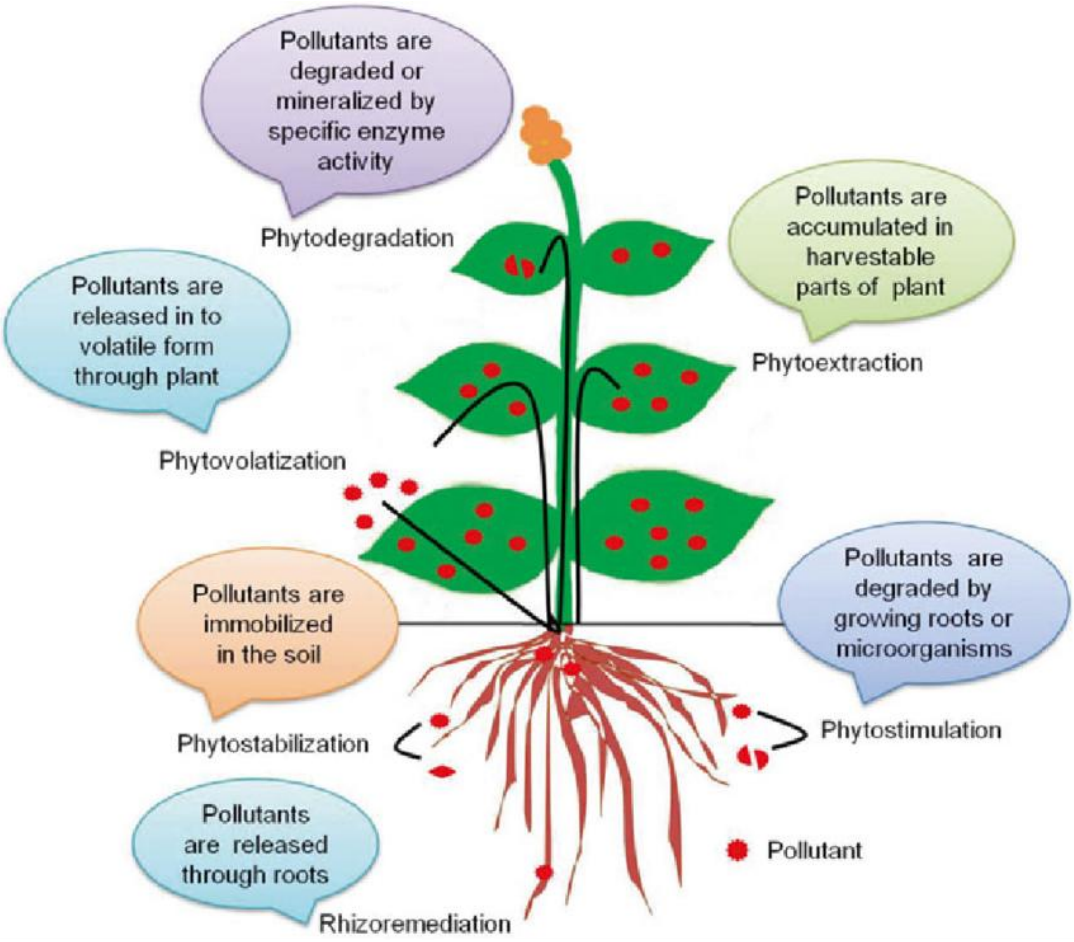
Rhizodegradation, also called enhanced rhizosphere biodegradation, phytostimulation, or plant-assisted bioremediation/degradation, is the breakdown of contaminants in the soil through microbial activity that is enhanced by the presence of the rhizosphere and is a much slower process than phytodegradation. Microorganisms (yeast, fungi, or bacteria) consume and digest organic substances for nutrition and energy. Certain microorganisms can digest organic substances such as fuels or solvents that are hazardous to humans and break them down into harmless products through biodegradation. Natural substances released by the plant roots—sugars, alcohols, and acids—contain organic carbon that provides food for soil microorganisms, and the additional nutrients enhance their activity. Biodegradation is also aided by the way plants loosen the soil and transport water to the area.

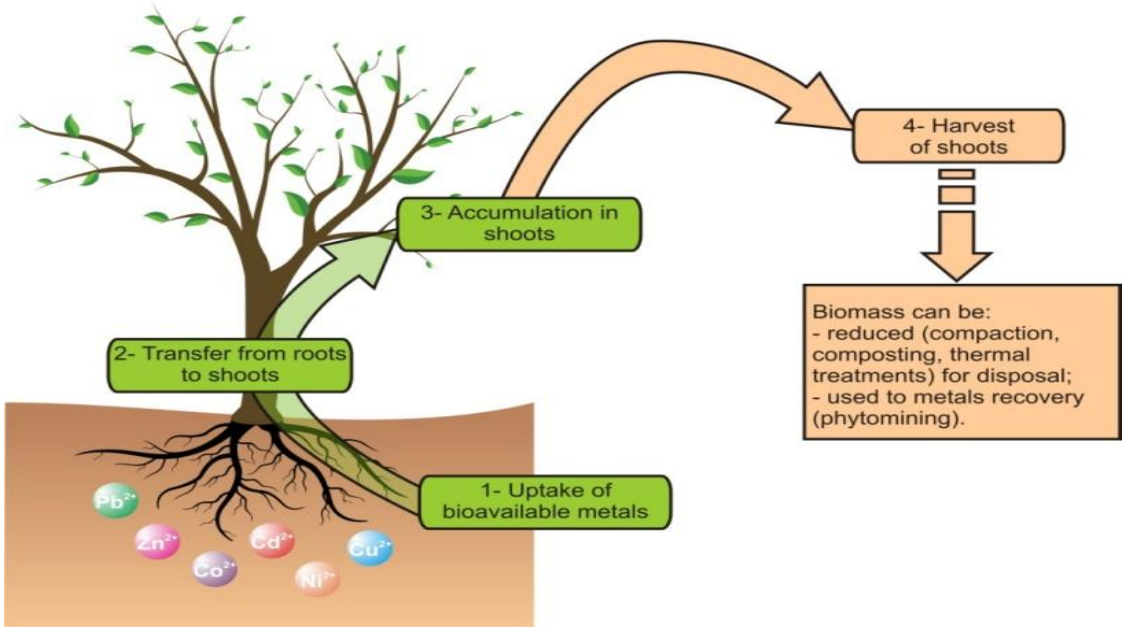
Phytovolatilization

Phytovolatilization is the uptake and transpiration of a contaminant by a plant, with release of the contaminant or a modified form of the contaminant to the atmosphere from the plant. Phytovolatilization occurs as growing trees and other plants take up water and the organic contaminants. Some of these contaminants can pass through the plants to the leaves and volatilize into the atmosphere at comparatively low concentrations.


Phytodegradation
(use of plants to destroy organic pollutants)
Phytovolatilization
(conversion of metals/metalloids to less toxic and volatile forms)
Phytoextraction
Metal chelation
Metal solubilization
Metals/metalloids
Metal immobilization
Toxicity reduction
Phytostimulation
(degradation of organic pollutants by plant root exudates)
Phytostabilization
Phytofiltration


Phytovolatilization: evaporation of certain metals from aerial parts of the plant
Phytoextraction: use of metal accumulating plants to remove toxic metals from soil
Heavy Metal
Phytostabilization: use of plants to eliminate the bioavailability of toxic metals in soils
Soil
Water
Rhizofilteration: use of plant to absorb, concentrate and precipitate contaminants from aqueous source


Pollutants are degraded or mineralized by specific enzyme activity
Phytodegradation
Pollutants are accumulated in harvestable parts of plant
Phytoextraction
Pollutants are released in to volatile form through plant
Phytovolatization
Pollutants are immobilized in the soil
Phytostabilization
Pollutants are degraded by growing roots or microorganisms
Phytostimulation
Pollutants are released through roots
Rhizoremediation
Pollutant


4- Harvest of shoots
3- Accumulation in shoots
Biomass can be:
- reduced (compaction, composting, thermal treatments) for disposal;
- used to metals recovery (phytomining).
2- Transfer from roots to shoots
1- Uptake of bioavailable metals
Pb2+
Zn2+
Cd2+
Cu2+
Co2+
Ni2+