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Phytoremediation (Plants as reactors)

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Abstract

Now -a- Days we have two types of treatment processes they are physiochemical process and biological process.in biological process ASP, trickling filters, RBC, oxidation ponds, and phytoremediation. At present phytoremediation is in the early stage of commercialization for treatment of wastewater containing organic and inorganic pollutants, and in the future it may provide a low cost option. In phytoremedition we use plants for treating waste water. In that roots are influent collectors and leaves are product delivers. In this we have six reactions takes place they are phytoextraction, rhizofiltration, phytostabilization phytodegradation, hizodegradation and phytovolatilization.Those plants also help prevent wind, rain, and groundwater from carrying pollutants away from sites to other areas. Wetland construction will help to remove or reconciliation of wastewater to environment from hazardous pollutants. Yellow or White Water Lillis, Alfalfagrass, these type of plants are useful to remove organic pollutants.Brassica family (Indian Mustard & Broccoli),Tomato plant, sunflower these are useful to remove inorganic pollutants. The paper will helps to understand the mechanism of phytoremediation and applications for developing countries.

Keywords:

phytoextraction, rhizofiltration, phytostabilization, phytodegradation, phytovolatilization, wetland construction.

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1. Introduction

The generic term 'phytoremediation' consists of the Greek prefix phyto (plant), attached to the Latin root remedium (to correct or remove an evil) (Cunningham et al., 1996). Phytoremediation is an alternative or complimentary technology. Phytoremediation is an in situ remediation technology that utilizes the inherent abilities of living plants. It is also an ecologically friendly, solar-energy driven clean-up technology, based on the concept of using nature to cleanse nature.

Phytoremediation is a broad term that has been used since 1991 to describe the use of plants to reduce the volume, mobility, or toxicity of contaminants in soil, groundwater, or other contaminated media (USEPA, 2000). Phytoremediation is a non-destructive and cost effective in situ technology that can be used for the cleanup of contaminated sites. The potential for this technology in the tropics is high due to the prevailing climatic conditions which favors plant growth and stimulates microbial activity (Zhang et al., 2010).

For at least 300 years, the ability of plants to remove contaminants from the environment has been recognized and taken advantage of in applications such as land farming of waste. Research into and application of phytoremediation has flourished over the last 15 years. Phytoremediation has been implemented as a component of the selected remedy at 18 Superfund sites in the United States (Wuana et al., 2010).

The objective of this review is to discuss the different phytoremediation mechanisms and their potentials as remediation techniques that utilize the age long inherent abilities of living plants to remove pollutants and its applications.

2. What kind of pollutants can be remove

This can judge by characteristics of pollutant. Pollutants can organic or inorganic both pollutants can remove by its mechanism

2.1. Organic pollutants generally present in:

- Domestic wastewater
- Phenol
- contaminants from TNT, pesticides, chlorinated solvents, and fuel/oil
- Toluene etc.,

2.2. Inorganic pollutants present in:

Heavy metals like

- Cadmium(Cd)
- Lead(Pb)
- Zinc (Zn)
- Cesium
- Strontium
- Mercury(Hg)
- Nickel(Ni)

Chlorine
Florien

2.3. What kind of plants we use

Some of the plants for organic pollutants used in phytoremediation are:

- Alfalfa
- Hybrid Poplar Trees
- Blue-green Algae
- Duck Weed
- Arrowroot
- Sudan Grass
- Rye Grass
- Bermuda Grass
- Alpine Bluegrass
- Yellow or White Water Lilies

Some of the plants for in organic pollutants used in phytoremediation are:

- Arabidopsis
- Bladder Campion
- Brassica family (Indian Mustard & Broccoli)
- Buxaceae (boxwood)
- Compositae family
- Euphorbiaceae
- Tomato plan
- Sunflower
- genus Lemma(Duckweed)

3. How Does Phytoremediation Work?

Plant roots take contaminants from the ground into the "body" of the plant. The plant root zone is referred to as the rhizosphere; this is where the action occurs. This soil supports large populations of diverse microorganisms. This is due to chemicals exuded by plant roots which provide carbon and energy for microbial growth. This combination of plants and microorganisms appears to increase the biodegradation of compounds.

4. Mechanisms:

Phytoremediation uses one basic concept: the plant takes the pollutant through the roots. The pollutant can be stored in the plant (phytoextraction), volatized by the plant (phytovolatization), metabolized by the plant (phytodegradation), or any combination of the above.

This review paper makes reference to six phytoremediation mechanisms, each explained in detail below. Each of these mechanisms will have an effect on the volume, mobility, or toxicity of contaminants, as the application of phytoremediation is intended to do (EPA, 2000).

4.1. Phytoextraction: This also called phytoaccumulation it is the uptake and storage of pollutants in the plants stem or leaves. Some plants, called hyper accumulators, draw pollutants through the roots. After the pollutants accumulate in the stem and leaves the plants are harvested. Then plants can be either burned or sold. Even if the plants cannot be used, incineration and disposal of the plants is still cheaper than traditional remediation methods. As a comparison, it is estimated a site containing 5000 tons of contaminated soil will produce only 20-30 tons of ash (Black, 1995).

4.2. Rhizofiltration: This is primarily used to remediate extracted groundwater, surface water, and wastewater with low contaminant concentrations. It is the adsorption or precipitation onto plant roots or absorption ofcontaminants in the solution surrounding the root zone. Rhizofiltration is typically exploited in groundwater (either in situ or extracted), surface water, or wastewater for removal of metals or other inorganic compounds (EPA, 2000).To acclimatize 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.

4.3. Phytostabilization: It 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 of plants (rhizosphere). This process reduces the mobility of the contaminant and prevents migration to the ground water and it reduces bio-availability of metal into the food chain. Phytostabilization can occur through the sorption, precipitation, complexation, or metal valence reduction.

4.4. Phytodegradation: It involves the degradation of complex organic molecules to simple molecules or the incorporation of these molecules into plant tissues (Trap et al., 2005). When the phytodegradation mechanism is at work, contaminants are broken down after they have been taken up by the plant. As with phytoextraction and phytovolatilization, plant uptake generally occurs only when the contaminants' solubility and hydrophobicity fall into a certain acceptable range.

4.5. Rhizodegradation: This is also referred to as phytostimulation. It refers to the breakdown of contaminants within the plant root zone, or rhizosphere. It is believed to be carried out by bacteria or other microorganisms whose numbers typically flourish in the rhizosphere.

4.6. Phytovolatilization: This involves the use of plants to take up contaminants from the soil, transforming them into volatile forms and transpiring them into the atmosphere (USEPA, 2000). Phytovolatilization also involves contaminants being taken up into the body of the plant, but then the contaminant, a volatile form thereof, or a volatile degradation product is transpired with water vapor from leaves (EPA, 2000). Phytovolatilization may also entail the diffusion of contaminants from the stems or other plant parts that the contaminant travels through before reaching the leaves (Raskin and Ensley 2000).

5. Applications:

Phytoremediation is more than just planting and letting the foliage grow; the site must be engineered to prevent erosion and flooding and maximize pollutant uptake. There are 3 main planting techniques for phytoremediation.

1. Growing plants on the land, like crops. This technique is most useful when the contaminant is within the plant root zone, typically 3 - 6 feet, or the tree root zone, typically 10-15 feet.
2. Growing plants in water (aquaculture). Water from deeper aquifers can be pumped out of the ground and circulated through a "reactor" of plants and then used in an application where it is returned to the earth (e.g. irrigation).
3. Growing trees on the land and constructing wells through which tree roots can grow. This method can remediate deeper aquifers in-situ. The wells provide an artery for tree roots to grow toward the water and form a root system in the capillary fringe.

Engineered wetland systems are good examples of phytoremediation techniques.
Subsurface plumes travel down-gradient and can undergo remediation along the way primarily through microbial attenuation reactions. As plumes reach shallower depths, they encounter the rhizosphere of upland plant communities where initial phytoremediation can begin. Eventually, groundwater flows outcrop and feed surfacewater flows. In this zone, diffuse plume contaminants are more accessible to phytoremediation activity and the plant communities are by definition wetlands. Wetlands by their positioning for shallow access to these contaminant plumes and their characteristically high productivity may represent the low-cost/high-value cleanup systems envisioned by EPA.

6. Engineered Wetlands:

Performance of CWS may be less consistent than in conventional treatments due to the environmental changes at different seasons.Engineered wetland systems (EWSs) thus designed to take advantage of ordinary CWSs.
Engineered wetlands (EWs) are special, advanced, semi-passive kinds of CWs in which operating conditions are more actively monitored, manipulated and controlled in such a manner as to allow contaminant removals to be optimized. At the same time, cold weather operability is improved in EWs, as is the ability to deal with otherwise adverse conditions and recalcitrant wastewaters such as landfill leachates and mine drainages.
All EWs are CWs, but not all CWs are EWs. With EWs, many kinds of biological and chemical process systems (e.g., aerobic and anaerobic bioreactors, limestone drains) can be "expressed" as cells of the system. EWs can be used to bridge the gap between active treatment and eventual.

6.1. Mechanismfor Wetlands:

Plants in a natural wetland provide a substrate (roots, stems, and leaves) upon which microorganisms can grow as they break down organic materials and uptake heavy metals. A constructed wetland (CW) is an artificial marsh or swamp, which have been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and their associated microbial assemblages to assist in waste treatment.
It usually consists of a number of individual rectangular and/or irregularly-shaped basins (cells) connected in series and surrounded by clay, rock, concrete or other materials. Three types of cells may be used in a constructed wetland system (CWS): free water surface (FWS) cells, sub-surface flow (SSF) cells, and hybrid cells that incorporate surface and subsurface flows

6.2. Ways to Engineer a Constructed Wetland:

Design modifications	Aeration in/under substrate beds to increase aerobic biodegradation rates Use of engineered SSF substrates in place of gravel to adsorb contaminants and control hydraulic loading
Process additions	Chemical and energy addition (eg. low grade heat) Dilution, alkaline streams
Vegetation changes	Plant harvesting for nutrient removal Phytoremediating plants, stress resistant species
Advanced operation methods	Recycle of effluents, intermediate streams Separation of competing reactions into different cells

Phytoremediation in EWs has been successfully tested in many locations worldwide, but full-scale applications are still limited due to a number of mechanism-related challenges. For example, assessing the phytoremediation potential of EWs is complex due to variable environmental conditions, the different actions of plants and their associated rhizosphere bacteria on contaminants.
The rate of biodegradation and mineralization during phytoremediation is usually affected by the nature and concentrations of contaminants present, as well as surrounding soil/air moisture, pH, temperature, soil elemental contents and their bioavailability, and the supportingmicrobial mediamoreover, the optimization of plant uptake of contaminants. The positive attributes forremediating contaminants provided by physico-chemical properties of wetlands, as well as the determination of thebest technical design parameters to achieve the maximum utilization of resources are challenging tasks forenvironmental engineers and researchers.
This review thus focuses on the mechanisms of phytoremediation in EWSs when reducing loads of variouscontaminants, as well as the applications of phytoremediation as an environmentally sound technology in EWSs. Phytoremediation in EWs have been successfully used to remove metals and organic contaminants from minewaste, agricultural runoff, and industrial effluent. The systems are typically less expensive and require lessmaintenance than traditional remediation technologies because they utilize naturally occurring physical, chemical,and biological processes to remove contaminants. The processes at work in treatment wetlands depend on thecharacteristics of plants, contaminants, and wetland physico-chemical properties.

6.3. Processes of plant uptake of contaminants:

The plants most often used in EWs are persistent emergent plants, such as bulrushes (Scirpus),spikerush(Efeocharis), and other sedges (Cyperus). Rushes (Juncus),common reed (Phragrnites),and cattails (Typha).Not allwetland species are suitable for waste treatment since plants for EWSs must be able to tolerate the combination ofcontinuous flooding and exposure to waste streams containing relatively high and often variable concentrations ofpollutants. The functions of wetland plants make them an important component of EWs. Plants contribute to contaminantremoval by altering hydrology, sequestering particulates, and accumulating pollutants. These processes can beutilized to design EWSs with a number of treatment approaches, which are mainly phytoextraction, rhizofiltrationand phytostabilization.

6.4. Popular plants for EWs:

Recommended Species	Maximum Water Depth*	Notes
Arrow arum (Peltandravirginica)	12 inches	Full sun to partial shade. High wildlife value. Foliage and rootstocks are noteaten by geese or muskrats. Slow grower. pH: 5.0-6.5.
Arrowhead/duck potato (Saggitarialatifolia)	12 inches	Aggressive colonizer. Mallards and muskrats can rapidly consume tubers.Loses much water through transpiration.
Blue flag iris (Iris versicolor)	3 - 6 inches	Attractive flowers. Can tolerate partial shade but requires full sun to flower.Prefers acidic soil. Tolerant of high nutrient levels.
Broad-leaved cattail** (Typhalatifolia)	12-18 inches	Aggressive. Tubers eaten by muskrat and beaver. High pollutant treatment,pH: 3.0-8.5.
Reed canary grass Phalaris(arundinocea)	6 inches	Grows on exposed areas and in shallow water. Good ground cover for berms
Spatterdock (Nupharluteum)	5ft,2ft minimum	Tolerant of fluctuating water levels. Moderate food value for wildlife, highcovers value. Tolerates acidic water (to pH 5.0).
Wild rice (Zizaniaaquatic)	12 inches	Requires full sun. High wildlife value (seeds, plant parts, and rootstocks arefood for birds). Eaten by muskrats. Annual, Non-persistent. Does notreproduce vegetatively.

*These depths can be tolerated, but plant growth and survival may decline under permanent inundation at these depths.

**Not recommended for stormwater wetlands because they are highly invasive, but can be used in treatment wetlands if approved byregulatory agencies.

Some factors including plant age and seasonal variation can influence the ability of a plant to uptakecontaminants. Optimization of such factors would help to increase the role of plants in EWs. Generally, young rootsgrow faster and have higher nutrient uptake rates than older roots. Seasonal changes in transpiration rates could change contaminant uptake rates and plume flow regulation by wetland plants.Creating mixtures of plant species is a possible strategy for phytoremediation of contaminant mixtures in theEWs. Contaminates in the environment often contain a combination of potentially hazardous chemicals.

Creatingwetlands with a mixture of plant species that vary in their affinity for each contaminant, could maximize the amountof contaminants removed, and ensures that remediation of multiple contaminants occurs simultaneouslyMeanwhile, a community of plants could maximize uptake throughout the growing season. In tropical or subtropicalareas, where the growing season lasts most or all of the year, a single plant species might be sufficient forphytoremediation. But in temperate and cold areas, using mixtures warm- and cool-season species could maximizethe length of the uptake season, thereby maximizing contaminant removal.Although plant species play a direct role in phytoremediation, their interaction with sediment microbes can playan equal or bigger role.

6.5. Physico-chemical properties of EWs:

The performance of contaminant removal from an engineered wetland is highly dependent upon physical andchemical properties of the system. Of these, the substrate may play a great role, and could very well be the factorthat is most amenable to control. The suitability of a passive technology, consisting of filters composed of a mixtureof limestone and sandstone rocks, for the treatment of landfill leachates were investigated.Seven substrates (bauxite,shale, burnt oil shale, limestone, zeolite, light expanded clay aggregates and fly ash) and seven monitoringparameters (pH, cation exchange capacity, hydraulic conductivity, porosity, specific surface area, particle sizedistribution and phosphate removal rate) were examined in a EWS.

Pollutant initial concentration and loading rates were found to influence the performance of EWS. Increasingloading rates and initial concentrations resulted in a decrease in dechlorination rates. As such, loading rates andinitial concentrations are important design considerations.

More physico-chemical parameters including pH, temperature, dissolved oxygen, salinity and amendment materials can impact the performance of a EWS. The use of a EWS consisting of a peat filter and a surface waterwetland for treatment of landfill leachate was investigated.Negative effects of physico-chemical properties in EWSs can be eliminated/managed through proper systemDesign.

Wetland systems, especially the constructed wetlands, have been used to treat a variety of wastes includingagriculture and mine drainages, secondary effluent, storm water, municipal, industrial and pulp and paper wastewater,as well as shallow soil and groundwater

Operations and Maintenance Requirements for Phytotechnologies

Operations Parameter	Maintenance Requirement
Soil conditions	Maintain soil amendments, soil pH, and fertilizer requirements
Irrigation system	Irrigation system may be needed to start plants and may be needed during drought conditions
Plant maintenance	Plants may need to be thinned, pruned, mowed and treated to control weeds
Fencing	Fencing may need to be installed to keep people and animals out. Fencing is an important safety factor when wetlands are used.
Replanting	Replanting will be required for annual plants. Replanting trees will be required if they are damaged or fail to grow.
Vector control	Phytotechnology applications attract mice, rats, starlings and other vectors that may be a nuisance. A suitable control plan will be needed.
Monitoring well maintenance	Monitoring wells will be needed and they require some maintenance.
Disposal of plant waste	Plant waste will need to be collected and disposed of properly. For some phytoremediationapplications, plant waste may need to be treated as a hazardous waste.
Stormwater runoff	Best management practices should be used to control stormwater runoff from the site
Mechanicalsupport systems	Maintenance will be required for mechanical systems
Wetlands systems	Pond maintenance, plant harvesting, influent and effluent monitoring, and sediment control will be required.

7. Advantages and Disadvantages to Phytoremediation:

7.1. Advantages:

1. Aesthetically pleasing.
2. Solar driven.
3. Works with metals and slightly hydrophobic compounds, including many organics.
4. Can stimulate bioremediation in the soil closely associated with the plant root. Plants can stimulate microorganisms through the release of nutrients and the transport of oxygen to their roots.
5. Relatively inexpensive - phytoremediation can cost as little as \$10 - \$100 per cubic yard whereas metal washing can cost \$30 - \$300 per cubic yard (Wantanbe, 1997).
6. Even if the plants are contaminated and unusable, the resulting ash is approximately 20-30 tons per 5000 tons soil (Black, 1997).
7. Having ground cover on property reduces exposure risk to the community (i.e. lead).
8. Planting vegetation on a site also reduces erosion by wind and water.
9. Can leave usable topsoil intact.

7.2. Disadvantages:

1. Can take many growing seasons to clean up a site.
2. Plants have short roots. They can clean up soil or groundwater near the surface in-situ, typically 3 - 6 feet (Ecological Engineering, 1997), but cannot remediate deep aquifers without further design work.
3. Trees have longer roots and can clean up slightly deeper contamination than plants, typically 10-15 feet (T. Crossman, personal communication, November 18, 1997), but cannot remediate deep aquifers without further design work (see Figure 2).
4. Trees roots grow in the capillary fringe, but do not extend deep in to the aquifer. This makes remediating DNAPL's in situ with plants and trees not recommended.
5. Plants that absorb toxic materials may contaminant the food chain.

6. Volatization of compounds can transform a groundwater pollution problem to an air pollution problem.
7. Returning the water to the earth after aquaculture must be permitted.
8. Less efficient for hydrophobic contaminants, which bind tightly to soil.

8. Conclusion:

As highlighted above, there are several ways in which plants are used to clean up or remediate contaminated sites. To remove pollutants from soil, sediment and/or water and air, plants can breakdown, or degrade organic pollutants or contain and stabilize inorganic contaminants by acting as filtersor traps.The success of phytoremediation at a given site cannot always be attributed to just one ofthese mechanisms because a combination of mechanisms may be at work.Phytoremediation is a lowcost, solar energy driven and natural cleanup technique, which are most useful at sites with shallow,low levels of contamination. They are useful for treating a wide variety of environmental contaminantsand are effective with or in some cases, in place of mechanical cleanup methods.

The mechanisms by which plants promote the removal of pollutants are varied, including uptake and concentration, transformation of pollutants, stabilization, and rhizosphere degradation, in which plants promote the growth of bacteria underground in the root zone that in turn break down pollutants. Phytoremediation is amenable to a variety of organic and inorganic compounds and may be applied either in situ or exsitu. In situ applications decrease soil disturbance and the possibility of contaminant from spreading via air and water, reduce the amount of waste to be land filled (up to 95%) and are low-cost compared with other treatment methods.

Phytoremediation in EWs is a promising alternative to treat wastes and an increasingly recognized pathway toadvance the treatment capacity of wetland systems. The performance of contaminant removal from an EW is highlydependent upon the characteristics of plants, wetland physico-chemical properties of the system and contaminantsthemselves. Factors including plant age andseasonal variations can influence the ability of a plant to uptake contaminants. Optimization of such factors wouldhelp to increase the role of plants in EWs. In cold regions, creating mixtures of plant species is a possible strategyfor phytoremediation of contaminant mixtures in the EWS. Multi-scaled applications of Phytoremediation in EWs have been reported worldwide. However, compared withthe cases of laboratory scales, full size applications are limited.

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