UNIT 12 PHYTOREMEDIATION

Structure

12.1 INTRODUCTION

Several methods employed for the treatment of a variety of wastewater are available *viz*., activated sludge, aerated lagoon, up-flow anaerobic sludge blanket digestion, reverse osmosis, ion-exchange, membrane bioreactor, trickling filter etc. However, these methods are quite expensive, which divert the industrialist's attention from treating the effluents and have become one of the most important detriments of any industry. Hence, there is an urgent need to develop simple and cost-effective technologies for treatment of effluents to reduce their pollution loads. Phytoremediation offers such a technology. Phytoremediation is *in situ* use of plants to stabilize, reduce, remediate, or restore contaminated ground water, sediment, soil or surface. It relies on plant's ability to act as a solar driven pumping and filtering system and enhances the natural tendency of ecosystem to restore itself. Phytoremediation is a technology that uses plants to treat soil and water contamination thereby reducing environmental pollution. Plants are used either to remove or to stabilize (hold in place) pollution in the soil. The ultimate goal is to use plants to reduce the risk of human exposure to various environmental hazards. Although, phytoremediation may take a long time, but it is often less-expensive compared to other methods used to remove toxic substances from the soil/ water. Another benefit is that it covers the site with an attractive layer of plants that prevents wind and water from carrying the pollution to other places.

The paradigm that all such plants can be used for environmental remediation is definitely very old and cannot be traced to one particular reference. Constructed wetlands, reed beds, floating plant systems, and aquatic weeds have been common for the treatment of waste waters for many years.

In this unit, we shall focus our attention, primarily on phytoremediation method to improve the environmental sustainability. We shall discuss the basic process involved in phytoremediation. Then we shall take up types of phtoremediation, process and mechanism, and its advantages, disadvantages and limitations. Subsequently we would study, phytoremediation in wetland ecosystem. We shall also talk about the role of genetically engineered plants.

12.2 OBJECTIVES

After reading this unit, you will be able to:

- define phytoremediation and its types;
- describe the various processes involved and mechanism of phytoremediation;
- understand the advantages, disadvantages and limitation of phytoremediation; and
- apply the phytoremediation in wetland ecosystems

12.3 DEFINITION, SCOPE AND TYPES

Phytoremediation comes from the Greek word phyto meaning "plant" and the Latin word remedium meaning "restoring balance”- the process of correcting a problem or to put back in proper condition.

12.3.1 What is Phytoremediation?

Phytoremediation is a bioremediation process that uses various types of plants to remove, transfer, stabilize, and/or destroy contaminants in the soil and groundwater and can be simply defined as the use of green plant to remove pollutants from the environment or to render them harmless. Phytoremediation is a green technology for clean environment and is a form of bioremediation and applies to all chemical or physical processes that involve plants for degrading or immobilizing contaminants in soil and groundwater. While the technology is not new, current trends suggest its popularity is growing. Several comprehensive reviews have been written on this subject, summarizing many important aspects of this low-cost plant-based technology by Cunningham *et al.* (1996); Cunningham and Ow (1996); Raskin *et al,* (1997); Salt *et al.* (1995); Salt *et al.* (1998) and Srivastava and

Purnima, (1998). The basic idea that plants can be used for environmental remediation is very old and cannot be traced to any particular source. However, a series of fascinating scientific discoveries combined with an interdisciplinary research approach have allowed the development of this idea into a promising, cost-effective and environment friendly technology. Phytoremediation can be applied to both organic and inorganic pollutants, present in solid substrates (*eg.*, soil), liquid substrates (*e.g.,* water) and the air.

12.3.2 Scope

Cunningham *et al.* (1997) defined phytoremediation as the use of green plant-based systems to remediate contaminated soils, sediments and water. Relative to many traditional techniques, phytoremediation is a fledgling technology intended to address a wide variety of surficial contaminants. Phytoremediation targets currently include contaminating metals, metalloids, petroleum hydrocarbons, pesticides, explosives, chlorinated solvents and industrial by-products. Watanabe (1997) defined phytoremediation on the brink of commercialization. Although phytoremediation has been tested on sites contaminated with petroleum products, heavy metals, munitions and radio nuclides and at abandoned mines, wood treatment sites, and sewage treatment sites, it remains unclear how large the phytoremediation market will be. Phytoromediation experts opine that the growth of interest in the field is driven by its relative cost-efficiency compared to standard remediation methods for government-mandated site clean-up.

Several workers have employed plants for the removal of organic and inorganic matters from the wastewater and soil. It is not exaggerated to compare green plants with that of lungs of nature with ability to uptake, tolerate and even hyper-accumulate heavy metals and toxic substances from soil and water through the roots and concentrate them in their various parts. Different phytoremediation applications to polluted/ contaminated soil and water are shown in Figure 5.1. Some of the aquatic weeds used for this purpose are in floating macrophytes based system *viz*., water hyacinth, water lettuce, salvinia and some species of duck weeds (Hammer, 1990; Mandi *et al.*, 1993), in submerged macrophytes based systems such as hydrilla, elodea, egeria and hornwort (*Ceratophyllum demersum*) (Brix and Schierup, 1989), in energent macrophytes based systems and wetlands *viz.*, common reed (*Phragmities australis*) (Hammer, 1990). In this context, *Eichhornia crassipes* particularly has received much attention, because of its high efficiency of removing pollutants from industrial wastewater (Jebanesan, 1997; Jain, 2000 and Narayana and Parvez, 2000).

12.3.3 Types of Phytoremediation

The following is a list of six different types of phytoremediation with explanations describing how they work:

a) **Phytosequestration**

Phytosequestration can also be termed as phytostabilization. It comprises of many different processes involving absorption by roots, adsorption to the surface of roots or the production of biochemicals by the plant that are released into the soil or groundwater in the immediate vicinity of the roots, and can sequester, precipitate, or otherwise immobilize nearby contaminants.

b) **Rhizodegradation**

Rhizodegradation takes place in the soil or ground water immediate **surrounding of the plant roots**. Under this process exudates from plants stimulate rhizospheric bacteria to enhance biodegradation of soil/ water contaminants.

c) **Phytohydraulics**

Phytohydraulics is the process to use deep-rooted plants like trees to contain, sequester or degrade ground water contaminants those come into contact with their roots. Poplar trees are such examples, which were used to contain a ground water plume of methyl-tert-butyl-ether (MTBE) (Hong *et al.* 2001).Poplar trees act as natural pumps to keep toxic herbicides, pesticides, and fertilizers out of the streams and groundwater as demonstrated by Environmental Protection Agency (EPA).

d) **Phytoextraction**

Phytoextraction is also known as phytoaccumulation. Plants take up or hyperaccumulate contaminants through their roots and store them in the stem or leaves tissues rather than degrade them. The contaminants are not necessarily degraded but are removed from the environment after harvesting the plants. This is useful especially in removing metals from soil and, in some cases, the metals can be recovered for reuse, by incinerating the plants, in a process called phytomining.

e) **Phytovolatilization**

Phytovolatalization is a process in which plants take up volatile compounds through their roots, and transpire the same compounds, or their metabolites, through the leaves, thereby **releasing them into the atmosphere**.

f) **Phytodegradation**

Phytodegradation is a process under which contaminants are taken up into the plant tissues where they are metabolized/destroyed, or bio-transformed. The transformation depends on the type of plants used, and can occur in roots, stem or leaves.

Check Your Progress Exercise 1

Put a tick (√) mark against the correct answer:

1) Phytoremediation is:

a) treatment of soil pollution through plants

b) treatment of air pollutants through plant

c) treatment of wastewater through plants

d) all of the above

2) Phytoremediation technology involves:

a) low-cost

b) high cost

c) no related to cost

d) none of the above

3) Rhizodegradation process includes:

a) stimulation of rhizospheric bacteria to enhance biodegradation of contaminants

b) hyperaccumulate contaminants through their roots

c) take up volatile compounds through roots and their transpiration

d) adsorption of contaminants to the surface of roots

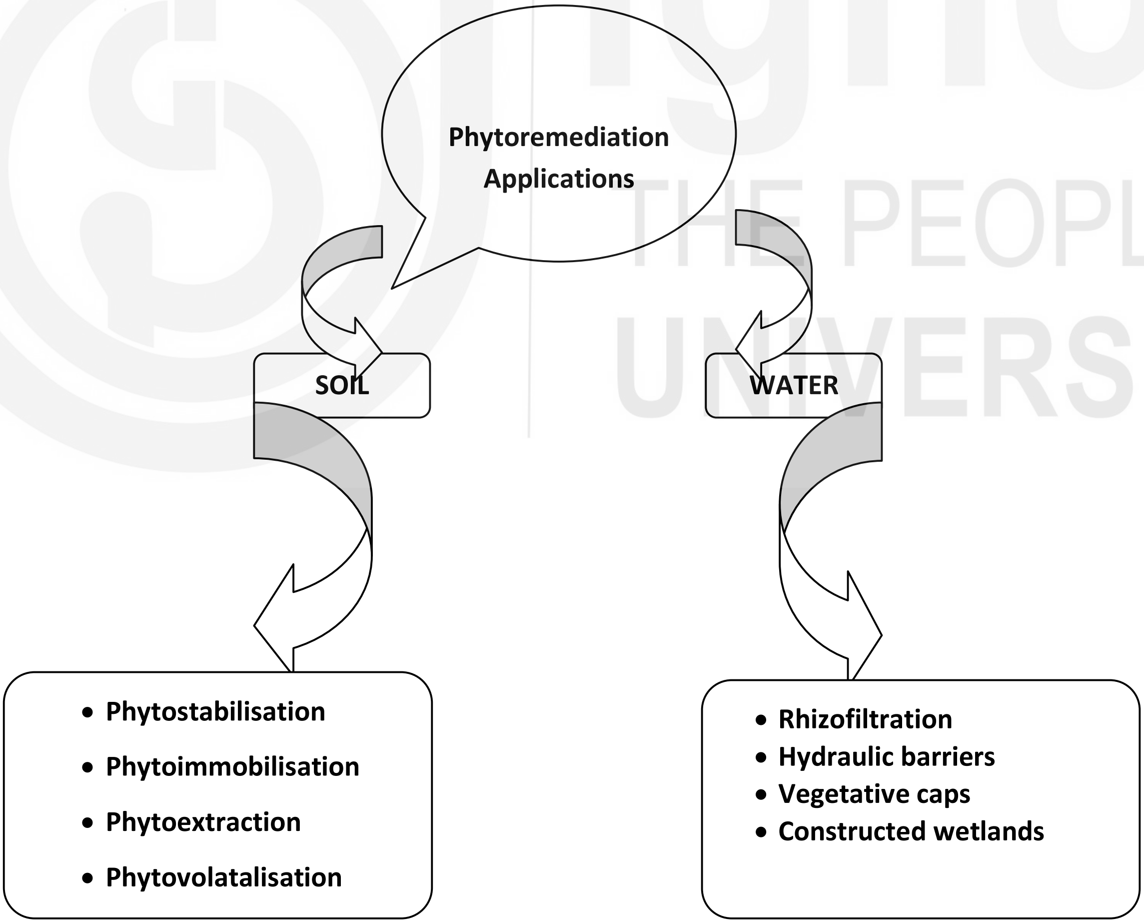
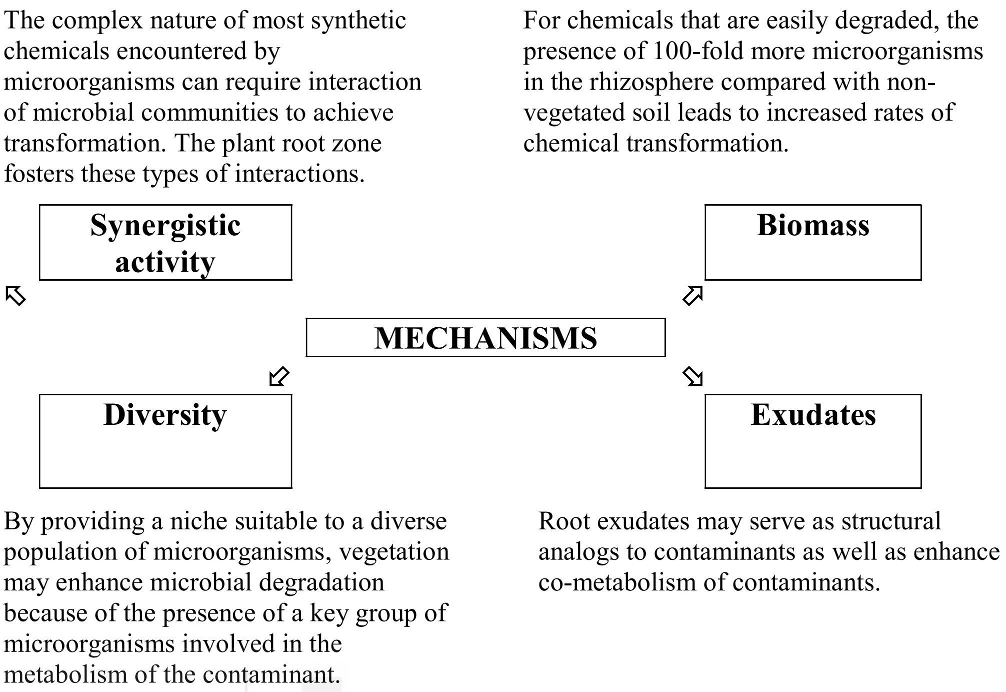


Fig. 12.1: Different phytoremediation applications to polluted/ contaminated soil and water



The complex nature of most synthetic chemicals encountered by microorganisms can require interaction of microbial communities to achieve transformation. The plant root zone fosters these types of interactions.

For chemicals that are easily degraded, the presence of 100-fold more microorganisms in the rhizosphere compared with non-vegetated soil leads to increased rates of chemical transformation.

By providing a niche suitable to a diverse population of microorganisms, vegetation may enhance microbial degradation because of the presence of a key group of microorganisms involved in the metabolism of the contaminant.

Root exudates may serve as structural analogs to contaminants as well as enhance co-metabolism of contaminants.

Fig. 12.2 Mechanism showing microbial degradation in the rhizosphere and its implications for bioremediation (Anderson and Coats, 1995)

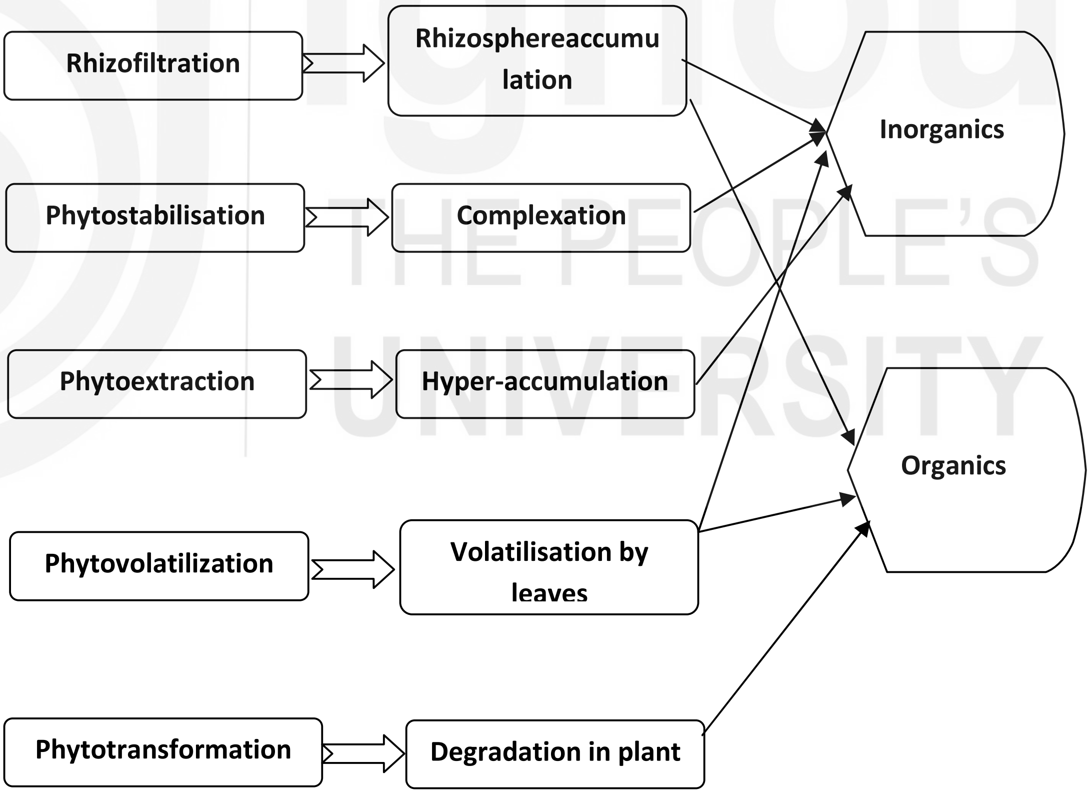


Fig. 12.3Phytoremediation includes the following processes and mechanisms of contaminant removal

12.4 PROCESS AND MECHANISM

Phytoremediation technique can be applied for inorganic/ organic compounds as well as for heavy metal removal.

12.4.1 Inorganics and Organics

Unlike the case with organic compounds that can be mineralized, the remediation of contamination with an inorganic contaminant must either physically remove the contaminant from the system or convert it into a biologically inert form. Removal can be accomplished by removing the biomass or, with certain inorganic contaminants, by contaminant' volatilization.

12.4.2 Heavy Metals

The plants with their sophisticated metabolic and for sequestration detoxification mechanisms, have the ability to accumulate essential heavy metals from soil and water which help in the plant growth like Fe, Mn, Zn, Cu, Mg, Mo, and Ni and non-essential heavy metals with unknown biological function like Cd, Cr, Pb, Co, Ag, Se, Hg. A lot of species of plants have potential in absorbing contaminants such as arsenic, cadmium, chromium, lead, and radionuclides from soils.

12.4.3 Process and Mechanism

Anderson and Coats (1995) presented an overview of microbial degradation in the rhizosphere and its implications for bioremediation (Fig. 5.2). This figure shows that the complex nature of most synthetic chemicals encountered by microorganisms can require interaction of microbial communities to achieve transformation. The plant root zone fosters these types of interactions. For chemicals that are easily degraded, the presence of 100 fold more microorganisms in the rhizosphere compared with non-vegetated soil leads to increased rates of chemical transformation. By providing a niche suitable to a diverse population of microorganisms, vegetation may enhance microbial degradation because of the presence of a key group of organisms involved in the metabolism of the contaminant. Root exudates may serve as structural analogs to contaminants as well as enhance cometabolium of contaminants.

Fig. 12.3 shows the variousprocesses and mechanisms of contaminant removal included in Phytoremediation, which are already discussed under section 12.4.3.

12.5 ENVIRONMENTAL FACTORS

The various factors involved for phytoremediation of contaminants were described in details by Anderson (1996). These factors are shown in Figure 5.4.

The following criteria were suggested by Abbasi and Ramasami (1999) over the years for selecting a plant species or combination of species as the main bioagent(s) in water treatment systems:

a) adaptability to local climate,

b) high photosynthetic rates-in other word, high growth rate,
c) high oxygen transport capability,
d) tolerance to adverse concentration of pollutants
e) high pollutant-uptake efficiency,
f) tolerance to adverse climate conditions,
g) resistance to pests and diseases, and
h) ease of management

The effectiveness of mechanical aeration in floating aquatic macrophyte based wastewater treatment system was studied by Debusk *et al.* (1989). Light aeration (0.003 and 0.021 Lm^{-2} min^{-1}) had no effect on the treatment of primary domestic effluent in the batch-fed water hyacinth tanks. Heavy aeration (1.03 and 3.53 Lm^{-2} min^{-1}) raised waste water dissolved oxygen (D.O.) concentrations but did not improve Biochemical Oxygen Demand (BOD_5) removal efficiency or increase plant growth rates during 21-days experiments. Debusk *et al.* (1991) reviewed wastewater treatment methods based on floating aquatic macrophytes in pond systems. Pennywort was the most efficient plant to provide secondary wastewater treatment, followed by water hyacinth and common duckweed. Similar study has been reported by Walsh *et al.* (1991) with *Echinochloa crusgalli* and *Sesbania macrocarpa*.

The phytoremediation experiments have been popular in several academic laboratories and industries (Brown, 1995). The plants called hyper-accumulators are categorized as the best for phytoremediation. They can be herbs, shrubs, and even trees. Hyper-accumulators concentrate trace elements, heavy metals or radio nuclides at level 100-fold or greater than normal.

Comis (1996) also described eco-friendly approach for remediation of soil *i.e.*, used plants to clean the soil. Cunningham and Ow (1996) described in details the promises and prospects of phytoremediation. Cunningham *et al.* (1999) described phytoremediation as an affordable technology that is most useful when contaminants are within the root zone of plants (top 3-6 ft [1-2 m]). He also reported various plants for the treatment of wastewater *viz.,Lemna, Pistia,* alfa alfa water hyacinth etc. Further popularization of phytoremediation technology from laboratory to the market place has been attempted by Dushenkov *et al.* (1997), Nyer and Gatliff (1996), Boyajian and Carreira (1997), Bishop (1997).

Plant's ability to absorb, translocate and concentrate metals has been studied by Chandra *et al.* (1997). The potential to accumulate chromium by *Scirpus lacustris, Phragmites karka* and *Bacopa monnicri* was assessed by subjecting them to different chromium concentrations under laboratory condition. The plants caused significant reduction in chromium concentrations. While there was an increase in biomass, no visible phytotoxic symptoms were shown by treated plants. Similar reports were made by Satyakala and Jamil (1997) with *Pistia stratiotes.*

Rice *et al.* (1997) conducted an investigation to test the hypothesis that herbicide-tolerant aquatic plants could remediate herbicide-contaminated water. The addition of *Ceratophyllum demersum* (Coontail, hornwort), *Elodea Canadensis* (American elodea, Canadian pondweed) or *Lemna minor* (common duckweed) significantly ($p \leq 0.01$) reduced the concentration of [^{14}C] metolachlor (MET) remaining in the treated water. Sarkar (1997) studied seasonal influence of the plant *Lemnamajor* in the treatment of eutrophicated ponds. The concentrations of total ammonical nitrogen (TAN), nitrate-nitrogen (NN) and phosphate of water in different seasons decreased in ponds exposed to aquatic plants and the mean percentages of nutrients in ponds with plants exhibited different trends and in the following orders: monsoon > winter > summer for TAN, monsoon > summer > winter for NN and summer > winter > monsoon for phosphate.

Using water lettuce plants, heavy metals can be effectively removed when they are present at a concentration of 10 mg/l or less (Selvapathy *et al.*, 1998). Siciliano and Germida (1998) described the mechanisms of phytoremediation. They further specified the biochemical and ecological interactions between plants and bacteria. Zayed *et al.* (1998) reported phytoaccumulation of trace elements by wetland plants *viz.*, duckweed.

Phytoremediation generally reduced B.O.D., NH_4^+-N, P, turbidity and volatile suspended solids. Populations of faecal coliforms were consistently reduced by 90 to 99 per cent by 2-days detention in microcosms with and without plants. Trivedy and Nakate (1999) studied aquatic weeds based waste water treatment plants in India and reported a very high degree of reduction in suspended solids, BOD and COD, nitrogen, phosphorous and oil and grease. Rose (2000) inferred that *Lemna minor* is efficient in removing BOD, solids and nutrients from the wastewater and has high potential for treating organically rich wastewater and reuse possibilities. Trivedy and Nakate (2000) studied treatment of diluted distillery waste by using constructed wetland on laboratory scale using *Typha latifolia.* The reduction in BOD and COD was 47.59 per cent and 78.77 per cent in 10 days. On the basis of above reports Central Pollution Control Board (CPCB, 2001) emphasized that phytoremediation is a natural biological treatment of wastewater.

Check Your Progress 2

Notes: a) Use the Space given for your answer.

b) Check your answer with the one given at the end of this unit.

1. Describe the various criteriafor selecting a plant species or combination of species as the main bioagent(s) in water treatment systems.

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12.6 ADVANTAGES, DISADVANTAGES & LIMITATIONS

Some of the advantages of phytoremediation technology are mentioned below:

- phytoremediation both *in situ* and *ex situ* is low cost treatment technology as compared to the traditional processes
- the plants used in the phytoremediation can be easily monitored
- the accumulated valuable metals in the harvested biomass can be recovered for reuse through "phyto mining" technique
- phytoremediation is eco-friendly and the least harmful method as it uses plants/ organisms occur in the nature, which also help to preserve the environment and ecological sustenance.
- phytoextraction can clean up the soil without causing any kind of harm to soil quality and its productivity.

Disadvantages

Contamination concentration, toxicity and bioavailability and Plant choice and stress tolerance are the main disadvantages of phytoremediation. Some of the reported disadvantages (Farraji *et al.,* 2016) are as below:

- Accumulation of pollutant in fruit and other edible parts of crop and vegetables.
- Growing of phytoremediator plants (hyperaccumulators)
- Low biomass production in phytoremediators, so several planting and harvesting required for decontamination
- Generally, specific selective unique accumulation of one metallic element in hyperaccumulator
- Environmental pollution caused by chelate–enhanced phytoremediation
- Very slow and seasonally effective treatment method
- Handling and disposing contaminated plants through the phytoremediation is the major foot print of this green technology
- Mobilization of radionuclides through the translocation in plants
- Not applicable for all compounds
- Dissolved contaminant in groundwater are not suitable case for aquatic phytoremediation

LIMITATIONS

There are always certain limitations while we use any technology. As such, phytoremediation technology has also its certain limitations, which are mentioned below:

- phytoremediation is limited to the surface area and depth occupied by the roots.
- slow growth and low biomass require a long-duration
- with plant-based systems of remediation, it is not possible to completely prevent the leaching of contaminants into the groundwater without the complete removal of the contaminated ground
- the survival of the plants is affected by the toxicity of the contaminated land and the general condition of the soil.
- The product produced during degradation may be accumulated in the animals via food materials obtained by plants, bio-accumulation of contaminants, especially metals, into the plants pass into the food chain, from primary level consumers to top level consumers
- the affected plant material requires the safe disposal
- as atmospheric layer stored the degraded materials for short period and via rain water it may again stored in ground water, the concerns are shown in the remediation of toxic contaminants through the phytoremediation process.
- Further research need to provide evidence that leaves fall down during autumn do not produce any contamination in the soil or fire wood also not release any gas which causes harmful effect to the environment.
- clearance of collecting plants can be difficult, if the amount of heavy metals is high.
- effectiveness mainly limits to surface or shallow soils and stream water.
- In-case of ground water treatment, pumping method is needed to collect the water, which is also added cost.
- effectiveness of phytoremediation is seasonal; due to plant development is mainly season based. A large area is required for cultivation of plants or tree used in phytoremediation.
- if contaminant concentrations are too high, plants may die.

12.7 PHYTOREMEDIATION IN WETLAND ECOSYSTEMS

Phytoremediation of metals is a cost-effective green technology based on the use of selected metal-accumulating plants to remove toxic metals from soils and water. Wetland plants are important medium in heavy metal removal. The Ramsar convention, one of the earlier modern global conservation treaties, was adopted at Ramsar, Iran, in 1971 and became effective in 1975. This convention emphasized the wise use of wetlands and their resources. In the convention, salient features of wetland ecosystems, their vegetation component, and the pros and cons involved in heavy metal removal were discussed extensively. Wetland plants are preferred over other bio-agents due to their low cost, frequent abundance in aquatic ecosystems, and easy handling. The extensive rhizosphere of wetland plants provides an enriched culture zone for the microbes involved in degradation. The wetland sediment zone provides reducing conditions that are conducive to the metal removal pathway. Constructed wetlands proved to be effective for the abatement of heavy metal pollution from acid mine drainage; landfill leachate; thermal power; and municipal, agricultural, refinery, and chlor-alkali effluent. The physicochemical properties of wetlands provide many positive attributes for remediating heavy metals. *Typha*, *Phragmites, Eichhornia, Azolla, Lemna*, and other aquatic macrophytes are some of the potent wetland plants for heavy metal removal. Biomass disposal problem and seasonal growth of aquatic macrophytes are some limitations in the transfer of phytoremediation technology from the laboratory to the field. However, the disposed biomass of macrophytes may be used for various fruitful applications like biogas production (Singhal and Rai, 2003) using anaerobic digestion, manure production and valuable metal recovery. Disposed biomass is stored solar energy in plant mass and materials having combustible organic matter. The main constituents of disposed biomass material are lignin, hemicellulose, cellulose, mineral matter and ash. Biogas production also ensures reducing odor, energy production and improve the storage and handling characteristics of manure. Genetic engineering and biodiversity prospecting of endangered wetland plants are important future prospects in this regard.

Relationship between phytoremediation and on-site treatment of septic effluents in sub surface flow constructed wetlands was studied by Neralla *et al.* (1999).

12.7.1 Natural Wetlands and Constructed/ Engineered Wetlands

Wetlands are inundated land areas with water depths typically less than 2 ft that can support the growth of emergent plants. Floating aquatic plants system contains the floating species such as water hyacinth and duck weed, where an average depth of water ranges from 1.6 - 6.0 ft. Supplementary aeration has been used with floating plant system for improved treatment efficiency and to maintain an aerobic condition for the biological control of mosquitoes. 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. However, as a result of the exponentially increasing demands of human expansion and resource exploitation, it has been recognized that natural wetland ecosystems cannot always function efficiently for desired objectives and stringent water quality standards. These and many other factors have led to the rapid development of "constructed wetlands" for waste (especially wastewater) treatment. 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 (Zhang *et al, 2001*). Phytoremediation in engineered wetland is an aesthetically pleasing, solar-driven, passive technique useful for cleaning up wastes including metals, pesticides, crude oil, poly-aromatic hydrocarbons, and landfill leachates and has become an increasingly recognized pathway to advance the treatment capacity of wetland systems.

12.8 ROLE OF GENETICALLY ENGINEERED PLANTS

Breeding programs and genetic engineering are powerful methods for enhancing natural phytoremediation capabilities, or for introducing new capabilities into plants. Genes for phytoremediation may originate from a micro-organism or may be transferred from one plant to another variety better adapted to the environmental conditions at the cleanup site. For example, genes encoding a nitroreductase from a bacterium were inserted into tobacco and showed faster removal of TNT (Trinitrotoluene-$C_6H_2(NO_2)_3CH_3$) and enhanced resistance to the toxic effects of TNT.Mechanism in plants has also been discovered that allows them to grow even when the pollution concentration in the soil is lethal for non-treated plants. Some natural, biodegradable compounds, such as exogenous polyamines, allow the plants to tolerate concentrations of pollutants 500 times higher than untreated plants, and to absorb more pollutants.

A plant is said to be a hyper accumulator if it can concentrate the pollutants in a minimum percentage which varies according to the pollutant involved (for example: more than 1000 mg/kg of dry weight for nickel, copper, cobalt, chromium or lead; or more than 10,000 mg/kg for zinc or manganese). This capacity for accumulation is due to hypertolerance, or *phytotolerance*: the result of adaptative evolution from the plants to hostile environments through many generations. A number of interactions may be affected by metal hyperaccumulation, including protection, interferences with neighbour plants of different species, mutualism (including mycorrhizae, pollen and seed dispersal), commensalism, and biofilm.

The understanding of phytoremediation reactions has recently progressed from basic uptake studies to quantifying the importance of chemical speciation for bioavailability and the role of genetic engineering for hyperaccumulating species. Genetic engineering of wetland plants may aid phytoremediation and more focused work is needed in this regard.

Check Your Progress 3

Notes: a) Use the Space given for your answer.

b) Check your answer with the one given at the end of this unit.

1. Write down the three major advantages and disadvantages of phytoremediation technology.

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2. What are wetlands?

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12.9 LET US SUM UP

The attention on vascular aquatic plants has been mainly directed towards their elimination from water bodies, since dense stands of these plants harm water resources in terms of quality as well as quantity. These plants adversely affect fisheries, impede navigation, hasten water loss, encourage insects, pests and disturb the fragile oxygen balance of water bodies through decay. Volumes of literature have been generated on methods to control the growth of aquatic plants. The negative characteristics of these weeds-hardiness, ability to survive under adverse environmental conditions and high productivity can be harnessed to make them efficient bioagents for treating wastewaters. Till recently, the successful exploitation of aquatic plants in this respect had been constrained by the lack of economically viable methods of post-harvest utilization of the ‘spent’ plants, but now it has been demonstrated that it is feasible to use such plants as energy feed stock, animal fodder, feed, biogas production and fertilizers. This has triggered considerable interest in aquatic macrophytes based wastewater systems (AMS). The economic success of energy production and water treatment using an AMS for water treatment/biomass production depends to a large extent on the photosynthetic activity and growth rate of plants.

12.10 KEY WORDS

Phytoremediation: Phytoremediation is a bioremediation process that uses various types of plants to remove, transfer, stabilize, and/or destroy contaminants in the soil and groundwater and can be simply defined as the use of green plant to remove pollutants from the environment or to render them harmless.

Wetlands: Wetlands are inundated land areas with water depths typically less than 2 ft that can support the growth of emergent plants

12.11 TERMINAL QUESTIONS

1) What is contamination? Write down its different types.

2) Write down the types of phytoremediation with explanations in your own words.

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3) Explain the mechanism involved in microbial degradation in the rhizosphere and its implications for bioremediation with the help of a suitable diagram.

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4) How genetically engineered plants are useful for phytoremediation?

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12.12 ANSWERS TO CHECK YOUR PROGREE EXERCISE

Check your Progress Exercise 1

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Check Your Progress Exercise 2

1) There are the following criteria for selecting a plant species or combination of species as the main bioagent(s) in water treatment systems:

   a) adaptability to local climate,
   b) high photosynthetic rates-in other word, high growth rate,
   c) high oxygen transport capability,
   d) tolerance to adverse concentration of pollutants
   e) high pollutant-uptake efficiency,
   f) tolerance to adverse climate conditions,
   g) resistance to pests and diseases, and
   h) ease of management

2) Hyper-accumulator plants concentrate trace elements, heavy metals or radio nuclides at level 100-fold or greater than normal.

Check Your Progress Exercise 3

1) Adantages:

a) phytoremediation both *in situ* and *ex situ* is low cost treatment technology as compared to the traditional processes
b) the plants used in the phytoremediation can be easily monitored
c) phytoremediation is eco-friendly and the least harmful method as it uses plants/ organisms occur in the nature, which also help to preserve the environment and ecological sustenance.

Disadvantages:

a) Accumulation of pollutant in fruit and other edible parts of crop and vegetables.
b) Very slow and seasonally effective treatment method
c) Handling and disposing contaminated plants through the phytoremediation is the major foot print of this green technology

2) Wetlands: Wetlands typically occur in topographic settings where surface water collects and ground water level remains near the surface, making the area wet through most period of the year.

Terminal Questions

1) Write from your own experience/ knowledge.

2) Refer section 5.2.3 for answer.

3) Anderson and Coats (1995) presented an overview of microbial degradation in the rhizosphere and its implications for bioremediation. The complex nature of most synthetic chemicals encountered by microorganisms can require interaction of microbial communities to achieve transformation. The plant root zone fosters these types of interactions. For chemicals that are easily degraded, the presence of 100 fold more microorganisms in the rhizosphere compared with non-vegetated soil leads to increased rates of chemical transformation. By providing a niche suitable to a diverse population of microorganisms, vegetation may enhance microbial degradation because of the presence of a key group of organisms involved in the metabolism of the contaminant. Root exudates may serve as structural analogs to contaminants as well as enhance cometabolium of contaminants. Refer Fig. 5.2.

4) Breeding programs and genetic engineering are powerful methods for enhancing natural phytoremediation capabilities, or for introducing new capabilities into plants. Genes for phytoremediation may originate from a micro-organism or may be transferred from one plant to another variety better adapted to the environmental conditions at the cleanup site.

12.13 SUGGESTED FURTHER READINGS/ REFERENCES

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