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Phytoremediation Techniques and Species for Combating Contaminants of Textile Effluents – An Overview

Ketan S. Kimmatkar[1], Prof. Abhay V. Purohit[2], Prof. A. J. Sanyal[3]

[1]Associate Professor, IDEAS – Institute of Design Education & Architectural Studies, Nagpur (MS), India
[2]Principal, IDEAS – Institute of Design Education & Architectural Studies, Nagpur (MS), India
[3]Professor & Ex-Principal, Manoharbhai Patel Institute of Engineering & Technology, Gondia (MS), India

Abstract: ***Increasing population is placing increasingly greater demand for the resources to meet their requirements. This leads to industrialization and consequent pressure on the existing natural resources. Increasing urban population and the consequent industrialization draw heavy quantity of water and provide a large quantity of wastewater effluent. The problems are further aggravating for disposal of these effluents. One of the important measures is using these effluents in tree plantations to control land degradation and improve environmental conditions. Dozens of remediation technologies developed internationally could be divided in two general categories incineration and non-incineration. Phyoremediation technology makes the use of the naturally occurring processes by which plants and their associated rhizospheric microflora degrade and sequester organic and inorganic pollutants Pollutant-degrading enzymes in plants probably originate from natural defense systems against the variety of chemicals released by pollutants. This system helps in natural and effective way of combating effluents in eco-friendly way.***

Keywords: Biomass, Contaminants, Species and *Phytoremediation.*

1. Introduction

Uneven distribution of rainfall, long dry spells, soil water stress and nutrient deficiency constitutes the major constraint in the establishment of planted tree seedlings in dry areas, where better quality water is becoming an increasingly scarce resource. Both the need to conserve water and to safely and economically dispose of wastewater, make the use of industrial effluent in tree plantation a very feasible option *(Singh and Bhati 2005)*. In many parts of the world, industrial wastewater is used for the irrigation of various crops including agronomic, horticultural and tree crops *(Mathur and Sharma 1984; Stewart et al. 1986; Urie 1986)*.

Trees and shrubs are a better alternative than agricultural crops because of high growth rates and potential to produce high biomass on annual basis. Trees have ability to sustain very high loading rate because of profuse root system to control leaching, salinity and toxicity of the soil and have no link with food chain.

1.2. Present day scenario with Textile Industrial Wastewater:

There are myriad of industries in the Indian arid zone utilizing substantial quantities of scarce water. Traditional textile finishing industry consumes about 100 liters of water to process about 1 kg of textile material. These industries are predominanatly more in number with respect to Vidarbha region of Maharashtra and parts of central India. Approximately around ten thousand different dyes and pigments are used industrially and over 0.7 million tons of synthetic dyes are produced annually throughout the world *(Gomare et al., 2009)*. In treating 1 ton of cotton fabric the composite waste stream may have 200 to 600 ppm BOD (biological oxygen demand), 1000 to 1600 ppm of total solids and 30 to 50 ppm of suspended solids contained in a volume of 50 to 160 m3 *(Hirschler, 1996)*.A very small amount of dye in water (10 to 50 mg/L) affects the aesthetic value, water transparency and gas solubility of water bodies *(Banat et al. 1996)*.

2. Physical and Chemical Methods for Remediation of Environmental Pollutants

The methods were applied depending on the source of contamination. Remediation of metal- contamination countenances a particular challenge, because unlike organic contaminants, metals cannot be degraded in their native toxic form to simpler, non/less toxic components hence must be removed. Dye wastewater is usually treated by physico-chemical treatment processes which include flocculation combined with flotation, electroflocculation, membrane filtration, electrokinetic coagulation, electrochemical destruction, ion-exchange, irradiation, precipitation, ozonation, and katox treatment methods. However, the physico-chemical treatments have numerous disadvantages, including high cost, low efficiency, and inapplicability, to a wide variety of metals, as well as formation of huge quantities of toxic by-products, further creating disposal problems of contaminated wastes *(Wani et al., 2007)*. Adsorption has been observed to be an effective process for color removal from dye wastewater. Many studies have been undertaken to investigate the use of low-cost adsorbents for color removal *(Ramakrishna and Viraraghavan, 1997; Crini,2006; Gupta and Suhas, 2009)*.

2.1 Types of Biological Remediation

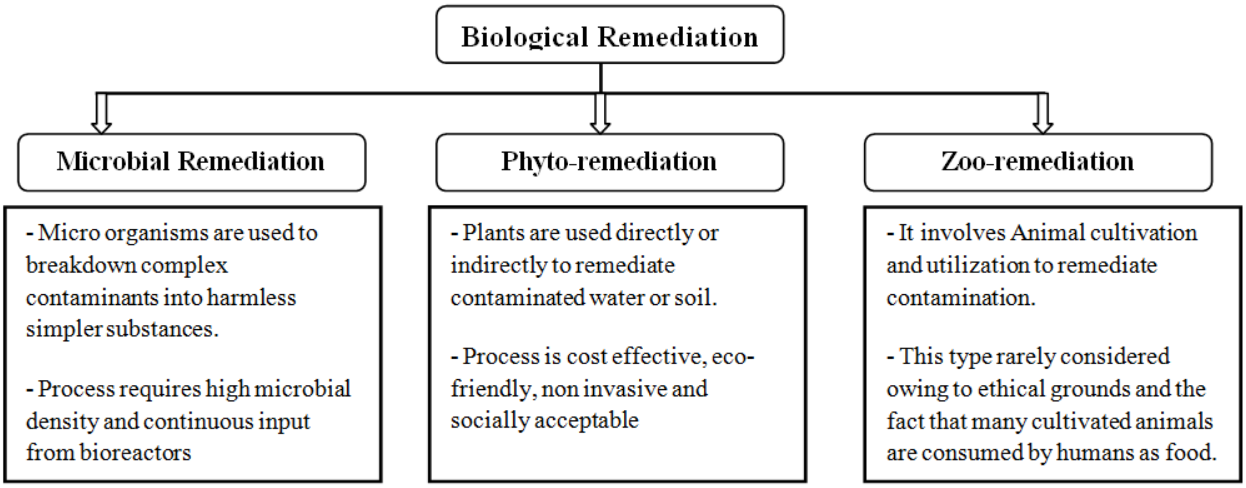

Figure 1: Bioremediation methods

2.2 Microbial Remediation of Environmental Pollution:

Considering the hazards and disadvantages of physico-chemical remediation processes, alternative approach is shifting towards the use of conventional biological methods to treat wastes *(Jadhav et al., 2010).* These methods are gaining more importance nowadays because of their lesser cost, effectiveness and eco-friendly nature. The metabolites produced after biodegradation are mostly non toxic or comparatively less toxic.

The use of microbes might lead to infections to humans that are why the method could not readily be used and required special restrictions. Obviously, there is an urgent need for alternative, cheap and efficient methods to clean up heavily contaminated industrial areas.

2.3 Phytoremediation: a Brief Overview- from a Concept to the Application

Phytoremediation is the use of plants and/or their associated microorganisms for the environmental cleanup. This is an emerging biotechnological application which operates on the principles of biogeochemical cycling *(Raskin and Ensley, 2000; Raju et al., 2008).* The term phytoremediation, from the Greek phyto, meaning ''plant'', and the Latin suffix remedium, ''able to cure'' or ''restore'', was coined by Ilya Raskin in 1994 and is used to refer to plants which can remediate a contaminated medium. Phytoremediation takes advantage of the plant's ability to remove pollutants from the environment or to make them harmless or less dangerous *(Raskin, 1996).* Phyoremediation technology makes the use of the naturally occurring processes by which plants and their associated rhizospheric microflora degrade and sequester organic and inorganic pollutants *(Pilon-Smits, 2005).*Pollutant-degrading enzymes in plants probably originate from natural defense systems against the variety of allelochemicals released by competing organisms, including microbes, insects and other plants *(Singer, 2006).*

2.4 Mechanism of Phytoremediation

Understanding the basic physiology and biochemistry that underlie various phytoremediation processes is very important to improve the applicability of this plant based method. In the following section (Table 2.2 and Figure 2.3), basic processes for phytoremediation are briefly summarized (Morikawa and Erkin, 2003).

2.5 Table 1: Differing areas of phytoremediation

Sr	Technology	Description
1	Phytostabilisation	Reduction of mobility and bioavailability of pollutants in environment
2	Rhizodegradation	Co-metabolic degradation of pollutants by soil rhizosphere microorganisms
3	Phytoextraction/ phytoaccumulation	Uptake of pollutants from environment and their concentration in harvestable plant biomass
4	Phytotransformation/ phytodegradation	Chemical modifications of pollutants as a result of plant metabolism, both in planta and ex-planta, often resulting in their invaction, degradation (phytodegradation) or immobilization (phytostabilisation)
5	Phytovolatilisation	Removal of pollutants from soil or water and their release into air, sometimes as a result of phytotransformation to more volatile and/or less polluting substances
6	Evapoptranspiration	Combined effects of plants both to evaporate water on their leaf surfaces and to vaporize water at the stomata
7	Rhizofiltration	Use of plant roots to absorb and adsorb pollutants or nutrients from water and wastewater (e.g. buffer strips)

Source: *Vamerali et al. (2010).*

2.6 Various techniques of Phytoremediation (Using Shrubs, Grasses, Aquatic plants Crops etc)

2.6.1 Phytostabilization:

Certain heavy metals and organic contaminants in soils can be concentrated and contained in the rhizosphere. This process is not to degrade but to reduce the mobility of the contaminant and prevent migration to the deeper soil or groundwater. Rhizosphere processes enhance the precipitation and conversion of soil pollutants to insoluble forms.

2.6.2 Rhizodegradation:

Plants are reported to excrete about 20% of the total photosynthesis products, including sugars, organic acids and amino acids, to the rhizosphere *(Campbell and Greaves, 1990)*, and thereby stimulating the growth of microorganisms. In the rhizosphere region (extending approximately 1 to 3 mm from the root surface), the proliferation of soil microorganisms can be 3 or 4 orders of magnitude greater than in nonvegetated soils *(Shimp et al., 1993)*.

2.6.3 Phytoaccumulation / Phytoextraction:

Phytoextraction refers to the extraction of metals or organics by plant roots from contaminated soil and water to translocate them to aboveground shoots. Metal hyperaccumulators are those plants which accumulate more than 1.0% (Mn) or 0.1% (Co, Cu, Pb, Ni, Zn), or 0.01% (Cd) of leaf dry matter *(Baker et al., 2000).*

2.6.4 Phytodegradation

In this technique of Phytodegradation, plants and associated microbes degrade organic pollutants *(Burken and Schnoor, 1997).* Phytodegradation is the uptake, metabolizing, and degradation of contaminants within the plant, or the degradation of contaminants in the soil, sediments, sludges, ground water, or surface water by enzymes produced and released by the plant. Phytodegradation is not dependent on microorganisms associated with the rhizosphere. Contaminants subject to phytodegradation include organic compounds such as munitions, chlorinated solvents, herbicides, and insecticides, and inorganic nutrients. Phytodegradation is also known as phyto- transformation, and is a contaminant destruction process

2.6.5 Phytovolatilization:

This is the volatilization through stomata of volatile chemicals taken up by plants from the media. Phytovolatilization of trichloroethylene (TCE) by poplar *(Chappell, 1998)* and methyl tertiarybutyl ether (MTBE) by eucalyptus *(Newman et al., 1999)*, selenium by Indian mustard *(de Souza et al., 2000)* and methyl mercury by tobacco *(Heaton et al., 1998)* and by yellow poplar *(Rugh et al., 1998)* have been reported. Once volatilized, these compounds may be degraded by hydroxyl radicals in the atmosphere or stay as an air pollutant.

2.6.6 Evapotranspiration:

Evapotranspiration mechanism is attributed to the combined effects of plants both to evaporate water on their leaf surfaces and to vaporize water at the stomata. This process is used in hydraulic control of groundwater *(Viessman et al., 1989)*. Mature phreatophyte trees such as poplar, eucalyptus and river cedar, which are known to be deep-rooted, typically can transpire (200 to 1100) liters of water per day out of the ground. Hardwood trees transpire about half the water of a phreatophyte.

2.6.7 Rhizofiltration:

Rhizofiltration refers to the approach of using hydroponically cultivated plant roots to remediate contaminated water through absorption, concentration, and precipitation of pollutants.

2.6.8 Phytoextraction

Phytoextraction is an aspect of phytoremediation that involves the removal of toxins, especially heavy metals and metalloids, by the roots of hyperaccumulator plants with subsequent transport to aerial plant organs which are able to accumulate concentrations up to 100-fold more than those normally found in non-accumulators species (Brunetti et al., 2011). A number of plants have been studied for Cr uptake that included, Prosopis sp., Typha angustifolia, and Convolvulus arvensis (Haque et al., 2009; Dong and Wu, 2007; Gardea-Torresdey et al., 2004). In addition, Leersia hexandra Swartz and Salsola kali have been reported as Cr hyperaccumulator (Zhang et al., 2005; De la Rosa et al., 2007). Moreover, Prosopis and C. arvensis have been accounted to tolerate, uptake, and reduce Cr(VI) to the less toxic Cr(III) (Aldrich et al., 2003; Montes-Holguin et al., 2006).

2.7. Recent studies reports on Phytoremediation:

Phytoremediation has been implemented for environmental remediation since 1980s and its applicability is still underway of progress for sustainable remediation. A lot of advancement has been progressed in the utilization of plants for cleaning up environment. The Table 2 summarizes the recent research carried out worldwide. In the present thesis, out of various pollutants mentioned so far, phytoremediation of textile dyes, pesticides from Troysan S89 and heavy metal (chromium) has been discussed comprehensively. Plants are natural attenuators to stress in the environment usually possessing properties to detoxify their surroundings, and may be suitable for use in phytoremediation Plants have also shown to possess metabolic pathways for degradation of textile dyes *(Kagalkar et al., 2009, Patil et al., 2009).* Phytoremediation dominates over microbial and other physico-chemical methods because of cost effectiveness, safety, easiness to manage due to the autotrophic system of larger biomass requiring little nutrient inputs *(Cunningham and Berti, 2000).*

Table 2: Recent selected examples of phytoremediation

Pollutant	Plant species	Summary	Reference
Organic			
Textile dyes			
Red HE7B	Nopalea cochenillifera Salm. Dyck.	Cactaceae N. cochenillifera cell cultures and intact plants (cladodes) transformed various toxic textile dyes, including Red HE7B into less phytotoxic, non-hazardous metabolites.	Adki et al. (2011)
Malachite Green	Blumea malcolmii Hook	Phytodegradation of triphenylmethane dye Malachite Green mediated by cell suspension cultures of B. malcolmii	Kagalkar et al. (2011)
Methyl orange	Brassica juncea L.	Biochemical characterization of laccase from hairy root culture of B. juncea L. and role of redox mediators to enhance its potential for the decolorization of textile dyes.	Telke et al. (2011)
Brilliant Blue R	Typhonium flagelliforme	In vitro cultures of T. flagelliforme decolorized a variety of dyes, along with Brilliant Blue R, to varying extents within 4 days.	Kagalkar et al. (2010)
Direct Red 5B	Blumea malcolmii	Tissue cultured shrub plants of B. malcolmii decolorized Malachite green, Red HE8B, Methyl orange, Reactive Red 2 but potently Direct Red 5B	Kagalkar et al. (2009)
Remazol Black B	Zinnia angustifolia	Consortium ZE degraded efficient and faster RBB when compared to degradation by Z. angustifoila and E. aestuarii individually	Khandare et al. (2011)
Navy Blue HE2R	Portulaca grandiflora Hook.	Wild and tissue cultured plants of P. grandiflora decolorized a sulfonated diazo dye Navy Blue HE2R up to 98% in 40 h.	Khandare et al. (2011)
Remazol Red	Aster amellus Linn.	Potential of A. amellus to decolorize a sulfonated azo dye Remazol Red, a mixture of dyes and a textile effluent	Khandare et al. (2011)
Remazol Orange 3R, Green HE4B	Aster amellus Linn, Glandularia pulchella (Sweet) Tronc.	Plant consortium-AG of A. amellus and Glandularia pulchella (Sweet) Tronc. showed complete decolorization of a dye Remazol Orange 3R in 36 h, while individually A. amellus and G. pulchella took 72 and 96 h respectively.	Kabra et al. (2011)
	Glandularia	Phytoremediation ability of G. pulchella in degrading Green	Kabra et al. (2011)
	pulchella (Sweet) Tronc.	HE4B into non-toxic metabolites.	
Green HE4B	Sesuvium portulacastrum	Potential of Sesuvium for the efficient degradation of textile dyes and its efficacy on saline soils contaminated with toxic compounds.	Patil et al. (2011)
Reactive Red 198	Tagetes patula L. (Marigold)	Degradation analysis of Reactive Red 198 by hairy roots of T. patula	Patil et al. (2009)
Acid orange 7	Phragmites australis	The role of antioxidant and detoxification enzymes of P. australis (a sub-surface vertical flow constructed wetland), in the degradation of acid orange7	Carias et al. (2008)
		The role of peroxidases extracted from the vertical flow constructed wetland P. australis leaves in the decolourization of AO7	Carias et al. (2007)
		Integrated study of the role of P. australis in azo-dye treatment in a constructed wetland: From pilot to molecular scale.	Davies et al. (2009)
		Phytoremediation of textile effluents containing azo dye by using Phragmites australis in a vertical flow intermittent feeding constructed wetland	Davies et al. (2005)
Textile wastewater	Typha angustifolia Linn.	A constructed wetland model for synthetic reactive dye wastewater treatment by narrow-leaved cattails	Nilratnisakorn et al. (2009)
		Synthetic reactive dye wastewater treatment by narrow-leaved cattails (T. angustifolia): Effects of dye, salinity and metals.	Nilratnisakorn et al. (2007)
polymeric dye R-478	Mentha pulegium	Peroxidase activity and phenolic content in elite clonal lines of M. pulegium in response to R-478 and Agrobacterium rhizogenes.	Strycharz and Shetty (2001)
dye solutions of different colors	Helianthus annuus	Phytoremediation of textile dyes used as a scientific experiment or demonstration in teaching laboratories of middle school, high school and college students.	Ibbini et al. (2009)
Organic			
Halogenated hydrocarbons			

Pollutant	Plant species	Summary	Reference
2,4-Dichlorophenol (2,4-DCP)	tobacco (Nicotiana tabacum cv. Wisconsin)	Tobacco hairy roots efficiently transformed high concentrations of 2,4-DCP in the medium to products with the lignin-type nature, which is compartmentalized in hairy root cell walls.	Talano et al. (2010)
Inorganic (metals and metalloids)			
Chromium			
Pollutant	**Plant species**	**Summary**	**Reference**
	Crambe abyssinica	Identifying genes and gene networks involved in chromium metabolism and detoxification in Crambe abyssinica.	Zulfiqar et al. (2011)
	Spirodela polyrrhiza	Phytoremediation of Cr(VI) by Spirodela polyrrhiza (L.) Schleiden employing reducing and chelating agents.	Bala and Thukral et al. (2011)
	rice (Oryza sativa L.), paragrass (Brachiaria mutica), and an aquatic weed (Eichhornia crassipes)	Bio-concentration of chromium-an in situ phytoremediation study at South Kaliapani chromite mining area of Orissa, India.	Mohanty et al. (2012)
	water spinach (Ipomonea aquatica)	Phytoremediation of Cr(III) by I. aquatica from water in the presence of EDTA and chloride.	Chen et al. (2010)
	hybrid willows	Effect of temperature on phytoextraction of hexavalent and trivalent chromium by hybrid willows	Yu et al. (2010)
Arsenic			
Pollutant	**Plant species**	**Summary**	**Reference**
	Hydrilla verticillata (L.f.) Royle	The accumulation of As in the shoot and immobilization of As below ground in roots proved H. verticillata as a potential As phyto filtrator for bioremediation	Xue and Yan (2011)
	maize (Zea mays L.)	Identification of QTLs for arsenic accumulation in maize using a RIL population.	Ding et al. (2011)
	Pityrogramma calomelanos and Pteris vittata L.	Phytoremediation potential of P. calomelanos var. austroamericana and P. vittata L. grown at a highly variable arsenic contaminated site.	Niazi et al. (2011)
	hyacinth	Batch and continuous removal of arsenic using hyacinth roots.	Govindaswamy et al. (2011)
	cottonwood	Enhanced arsenic tolerance of transgenic eastern cottonwood plants expressing gamma-glutamylcysteine synthetase.	LeBlanc et al. (2011)
Cadmium			
Pollutant	**Plant species**	**Summary**	**Reference**
	Alyssum species.	Cadmium phytoextraction potential of different Alyssum species.	Barzanti et al. (2011)
	Ricinus communis	The phytoremediation potential of bioenergy crop R. communis for DDTs and cadmium co-contaminated soil	Huang et al. (2011)
	Solanum nigrum L.	In-situ cadmium phytoremediation using S. nigrum L.: the bio- accumulation characteristics trail.	Ji et al. (2011)
		S. nigrum effective in phytoextracting Cd and enhancing the biodegradation of PAHs in the co-contaminated soils with assistant chemicals (EDTA, cysteine, salicylic acid, and Tween 80).	Yang et al. (2011)
	Arabidopsis thaliana	Heterologous expression of a N. nucifera phytochelatin synthase gene enhances cadmium tolerance in A. thaliana.	Liu et al. (2011)
		Expression of the bacterial heavy metal transporter MerC fused with a plant SNARE, SYP121, in A. thaliana increases cadmium accumulation and tolerance.	Kiyono et al. (2011)
	Solanum nigrum	Chemical-assisted phytoremediation of CD-PAHs contaminated soils using S. nigrum L.	Yang et al. (2011)
Lead			
Pollutant	**Plant species**	**Summary**	**Reference**
	buttonwood	Phytoremediation of lead in urban polluted soils in the north of Iran	Hashemi (2011)
	willow varieties	The pot experiment suggested that Salix varieties have the potential to take up and translocate significant amounts of Pb into above-ground tissues using EDTA.	Zhivotovsky et al. (2011)
Nickel			

Pollutant	Plant species	Summary	Reference
	rape shoots (Brassica napus L.)	Nickel accumulation in rape shoots (B. rassica napus L.) increased by putrescine.	Shevyakova et al. (2011)
Miscellaneous			
Pollutant	**Plant species**	**Summary**	**Reference**
Fe, Cu, Zn, Ni, Al, Cr, Pb, Si, and As	Pteris vittata L.	P. vittata is confirmed to be a heavy metals accumulator and a highly suitable candidate for phytoremediation of metal contaminated wastelands.	Kumari et al. (2011)
Cd, Cr, Cu, Mn, Fe, Ni, Pb and Zn	Phragmites cummunis,Typha angustifolia, Cyperus	Phytoremediation of Cd, Cr, Cu, Mn, Fe, Ni, Pb and Zn from aqueous solution using Phragmites, Typha and Cyperus.	Chandra and Yadav (2011)

3. Various techniques of Phytoremediation (Using Trees)

Under the situations where land has already been contaminated and food crops are not permitted; Other indigenous forest species surviving in stern conditions such as Luecaena leucocephala, Prosopis juliflora, Butea monosperma, Madhuca indica, Albizia lebbeck, Pongamia glabbra Casuarina equisetifolia, Acacia auriculiformis, Acacia nilotca have shown better adaptability for soils with high acidity, alkalinity, nitrogen fixation and high tolerance to contaminants. Alternate land uses like establishment of manmade forests with high economic value and having high rate transpiring trees like sisal, mahogany, Eucalyptus, poplar, bamboo, neem (Azadirachta indica), shisham (Dalbergia sissoo) etc. for non- edible products like fuel and timber and developing green belts around the cities can be another approach to overcome pollution hazards. Under such species tyoe, the quality of groundwater has been observed to be not affected by effluent applications and the heavy metals in soil have also been observed to be low. Biochemical oxygen demand removal efficiency of tree plantations has also been observed to be 80.0 to 94.3% *(Thawale et al., 2006).* Hence, based on varying water demand in different seasons, area to be brought under high rate transpiration systems may be evolved.

4. Discussions

1. In particular, the use of fast-growing, bushy species, which can be readily grown under a short rotation coppice system, with harvests every 3 –5 years, show considerable promise. The fast growth and regular harvests lead to rapid uptake of nutrients, and hence also heavy metals, from the soil. Burning of the harvested wood to produce renewable bioenergy is also an attractive feature when considering the overall life cycle of the system.
2. Careful selection of the plant and plant variety is critical, first, to ensure that the plant is appropriate for the climatic and soil conditions at the site, and second, for effectiveness of the phytoremediation. Plant species that are long-term competitors and survivors under adverse changing conditions will have an advantage.
3. Crops vary in terms of tolerance to heavy metal concentration in soil. They also differ in terms of metal affinities and accumulation of assimilated heavy metals in different plant parts. Thus crops should be selected in such a way that they can tolerate the given toxic constituents of wastewater and accumulate in plant part which is of least importance or not consumed.
4. Depending upon the quantity and quality of the wastewater available for use, appropriate combination of wood trees, fruit trees, fodder, industrial crops and cereals should be formulated. Wastewater use in public park, golf course, green belts and tree plantation should be promoted.
5. Farmers should be encouraged to adopt modern methods of irrigation like drip. Combinations of emitter size, placements and filtration units need to be found for wastewater of different qualities for its better management.
6. Increased funding may be provided for research to design efficient, cost-effective, and sustainable natural wastewater treatment systems that conserve nutrients while effectively removing pathogens and other pollutants.
7. Similarly more research needs to be conducted to find remunerative crops with non- edible economic part to avoid food chain contamination and better phyto-remediation of polluted sites.
8. Local authorities, private companies and other bodies involved with the remediation of contaminated land should be encouraged to use phytoremediation, especially if budgets are limited and the alternative is that no treatment is carried out.
9. There is an opportunity to use these sites as demonstration and research areas. Collaboration with universities, research institutes and government bodies could create the multidisciplinary teams necessary to address questions such as: the agronomic practices needed for successful establishment of vegetation, development of plants for specific remediation requirements, the question of what constitutes 'clean-up' (bioavailable vs. total), effects of growing plants on the wider environment and fate and disposal of high metal biomass.

5. Conclusions

1. Root morphology and depth are important plant characteristics for phytoremediation. Root depth directly impacts the depth of soil that can be remediated or depth of ground water that can be influenced, as close contact is needed between the root and the contaminant or water.
2. Root depth varies greatly among different types of plants, and can also vary significantly for one species depending on local conditions such as depth to water,

soil water content, soil structure, depth of a hard pan, soil fertility, cropping pressure, contaminant concentration, or other conditions. The bulk of root mass will be found at shallower depths, with much less root mass at deeper depths.

3. A large root mass and large biomass may be advantageous for various forms of phytoremediation, for example, to allow a greater mass of metals accumulation, greater transpiration of water, greater assimilation and metabolism of contaminants, or production of a greater amount of exudates and enzymes.
4. Literature values for growth rates and biomass production may be from studies in which vegetation was grown under normal agricultural practices (i.e., in uncontaminated soil) and thus may not reflect the lower values that are likely to occur under stressed conditions in contaminated soils.
5. Terrestrial plants are more likely to be effective for phytoremediation than aquatic plants due to their larger root systems. Poplar (or hybrid poplar) and cottonwood trees, such as the Eastern cottonwood (Populus deltoides), are fast-growing trees (some can grow more than 3 m/year)
6. Indian mustard is a relatively high biomass and fast-growing accumulator plant which has the ability to take up and accumulate metals and radionuclides. Sunflower (Helianthus annuus) can accumulate metals and has about the same biomass as Indian mustard. Examples of metal hyperaccumulators that have been investigated include Thlaspi caerulescens (Alpine pennycress), but which is slow-growing and has a low biomass; Thlaspi rotundifolium spp. cepaeifolium , the only known hyperaccumulator of Pb and other Thlaspi species that can hyperaccumulate cadmium, nickel, or zinc.
7. Grasses have been investigated for rhizodegradation and phytostabilization due to their widespread growth and their extensive root systems. Examples include ryegrass, prairie grasses, and fescues. Some grasses, such as Festuca ovina, can take up metals but are not hyperaccumulators
8. Aquatic plants such as the floating plants water hyacinth (Eichhornia crassipes), pennywort (Hydrocotyle umbellata), duckweed (Lemna minor), and water velvet (Azolla pinnata) have been investigated for use in rhizofiltration, phytodegradation, and phytoextraction. These plants have been used in water treatment, but are smaller and have smaller, slower-growing root systems than terrestrial plants. Based on metals content and degree of bioaccumulation, it is found that duckweed could be an effective phytoremediator of cadmium, selenium, and copper in waste water.
9. Further found that water hyacinth was a promising candidate for phytoremediation of cadmium, chromium, copper, and selenium. Other aquatic plants that have been investigated include parrot feather, Phragmites reeds, and cattails.
10. There is still much fundamental and applied research needed to underpin phytoremediation technology, but this could be undertaken in conjunction with actual remediation schemes, which would achieve the dual purpose of treating contaminated sites and providing demonstration sites to show the application of phytoremediation.
11. Apart from Phytoremediation techniques to clean industrial wastewater and contaminated soils, Indigenous technical knowledge (ITK), local knowledge'' and "Traditional Knowledge should also be properly documented for safe and sustainable wastewater use.

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