Phytoremediation- A Green and Clean Technology for remediation of Industrial Contaminants

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***Abstract* -** In world of science and technology, along the global development new challenges of environment protection and conservation has been ahead. Almost every country of world raised voice for sustainable development. For sustainable development of a country, soil and water resources most valuable resources which are unfortunately maximum exploited and polluted in the race of development. The various harmful pollutants (organic as well as inorganic) in soil, air and water impacts both on natural resources and ecosystems. Phytoremediation is a new innovative technology that is cleaning of environment with the help of environment. Phytoremediation involves different plants which has been utilized to clean environment contaminants through different mechanism. Moreover, phytoremediation technology is cost effective as compare to other well-known methods to remediate industrial contaminants. Earlier, one major problem associated with this technology is production of large biomass after remediation process but now that biomass could be utilized in the form of bioenergy. This review focused on different phytoremediation mechanisms and their potential to remediate various pollutant especially heavy metal and textile dyes.

Keywords- Phytoremediation, contaminants, Heavy-metals, Textile Dyes.

I. INTRODUCTION

Phytoremediation is a new innovative and emerging technology that uses plants to degrade, extract, or immobilize contaminants from air, water and soil. As an innovative, cost effective and eco-friendly approach of phytoremediation technology receive more attention as compare to other alternative and established conventional methods used for cleaning pollutants. The conventional methods used for the treatment of contaminants such as leaching of pollutant, solidification/stabilization, electro-kinetical treatment of ionic species migrates to electrodes inserted into the soil, chemical precipitation, reverse osmosis , chemical oxidation and reduction, coagulation-flocculation, ion exchange, and ultra-filtration have multiple disadvantages such as release of toxic substances , formation of a large amount of sludge, cost-issue etc [1-2]. Because of which bioremediation methodologies can be used as alternative technologies for the removal of industrial wastes. Conventional techniques for bioremediation that involve the digging up of contaminated soils and disposal of the wastes to a landfill, lead to contamination elsewhere and can create significant risks in excavation, handling and transportation of hazardous material [3]. Microbial bioremediation processes for the removal of hazardous compounds, have received quite a lot of focus from researchers all over the world because of the high potentiality of microbes to perform a variety of functions. Microbial biodegradation has been somewhat successful for the degradation of certain organic contaminants and mainly but ineffective to toxic metal [4]. Although these conventional methods are used to clean majority of polluted sites as they are fast and can function over a wide range of oxygen, pH, temperature and osmotic potential but they also tends to be costly and disruptive to environment. The high cost of these technologies is primary driving force behind the search for alternative remediation technologies which have potential to be low-cost and low-impact. This concept is called as phytoremediation.

Though this technology has been used for hundreds of years to treat human wastes, reduce soil erosion and protect water quality, still the research focusing mainly on the phytoremediation of contaminated soils has only grown significantly in the last 25 years. The use of phytoremediation processes for the removal toxicants is comparatively less explored methodology since the fact that plants also possess some inherent metabolic pathways that can breakdown a wide range of toxicants [5] was much less realized a two decades ago. As researchers have now begun to realize the potential of plant systems as effective remediating agents, this new area of phytoremediation has started gaining importance from academician and industry [6]. As a result, phytoremediation is being developed as potential remediation solution for thousands of contaminated sites in the USA [7]. So, phytoremediation becomes a subject of intense public and scientific interest and a topic for current research. Phytoremediation become possible only because of the productive interdisciplinary cooperation of biologists, chemists, agronomists, environmental engineers and federal & state regulators.

Phytoremediation takes advantages of the fact that a living plant can be considered a solar-driven pump, which can extract and concentrate elements or compounds from surrounding environment. Phytoremediation also avoids the need for soil excavation and transport and causes less disruption to ecosystems than physical, chemical or microbial remediation [8]. Phytoremediation can also help in controlling run off, soil erosion, lower air, water emissions and secondary waste production thus making it an attractive technology. This technology also offer a modest way to decrease the effects of global change by lowering energy usage, CO_2 and other harmful gases emission and waste emission during waste water treatment [9].Therefore, the value of plants to counter balance the hazards of industrialization processes is being appreciated [10]. Phytoremediation can thus serve dual purposes. The release of large amount of toxic wastes into water bodies is one of the consequences of increasing urbanization and industrialization in the modern world. A variety of organic (pesticides, explosives such as TNT, petrochemicals, chlorinated solvents, dyes etc.) and inorganic (heavy metals such as mercury, lead, etc) wastes which have toxic effects on the ecosystem have been contaminating our natural resources [6]. So it is very urgent need to remediate dye bearing effluent by such type of emerging technology. The removal of textile dyes mediated by plant systems is still a much unexplored area of phytoremediation research. Hence, there is wide scope of removal of pollutant with Phytoremediation method. The present research aims at unraveling the remediation potential and mechanism of different plants to remediate industrial effluent and explore the basic mechanism and the application of these technologies for actual practices which will helps to broaden the horizons of phytoremediation technologies.

II. PHYTOREMEDIATION OF HEAVY METALS

Among various water pollutants, heavy metals are of major concern because of their bio-accumulative nature & carcinogenic and mutagenic effects with a potential toxicity to all life forms [11-12]. Heavy metals are metallic chemical elements with a high atomic weight and density much greater (at least five times) than water. They are highly toxic and cause ill effects at very low concentrations e.g. mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), thallium (Tl), and lead (Pb) [13]. A number of research reports has been published on heavy metal remediation by aquatic plants. This area can be further explored.

Among the various terrestrial plants, which involve in phytoremediation process, a very few are listed in table1.

Table 1: Terrestrial plants known for their potential to accumulate heavy metals

Plant	**Heavy metal**	**References**	**Plant**	**Heavy metal**	**References**
Lactuca sativa	As, Pb	[15]	Black gram	Cd	[20]
Lupinus luteus	Pb, Cu, Cd,	[16]	Mustard and pumpkin	Cd	[21]
Orychophragmus violaceus.	Zn	[17]	Maize and tomato	Cd, Pb	[22]
Maize	Cr, Pb	[18]	Sedum alfredii	Cd, Zn	[23]
Brassica juncea	Pb, Zn, Cu	[19]	Barley cultivar	Pb,Cd	[24]
Pteris vitata	As	[25]	Alfa-alfa and Sorghum bicolor	Cr	[26]
Helianthus indicus	Cu	[27]	Bryophyllum pinnatum	Cd, Cr,Cu	[28]
Euclayptus	Pb,Zn, Cu	[29]	Spartina	Cr,Co, Ni	[30]
French marigold	Zn	[31]	Kalanchoe	Cu	[31]
Euphorbia	Cd	[32]	Helianthus	Pb	[33]

But it was found that aquatic macrophytes are more suitable for wastewater treatment than terrestrial plants because of their faster growth and larger biomass production, relative higher capability of pollutant uptake, and better purification effects due to direct contact with contaminated water. Their ability to hyperaccumulate heavy metals make them interesting research candidates especially for the treatment of industrial effluents and sewage waste water [13]. Table 2 summarizes on phytoremediation potential of some aquatic macrophytes.

Table 2: Aquatic macrophytes known for their potential to accumulate heavy metals

Aquatic Plant	**Heavy metal**	**Accumulation (dry weight basis)**	**References**
Eichhornia crassipes	Zn, Cu, Ni	9.26 - 112.5mg kg^{-1} 2.5 – 19.0 mg kg^{-1} 0.5 – 2.2 mg kg^{-1}	[34]
	Hg	119 mg Hg g^{-1}	[35]
	Cd	3992 µg Cd g^{-1}	[36]
	Cu	314 µg Cu g^{-1}	[37]
	Cr, Cd, Ni	2.31 mg Cr g^{-1} 1.98 mg Cd g^{-1} 1.68 mg Ni g^{-1}	[38]
	Cr	1258 µg Cr g^{-1}	[39]
Elodea densa	Hg	177 ng Hg g^{-1}	[35]
Eleocharis acicularis	Fe, Pb, Zn, Mn, Cr, Cu, Ni	500 µg Fe g^{-1} 1120 µg Pb g^{-1} 964 µg Zn g^{-1} 388 µg Mn g^{-1} 265 µg Cr g^{-1} 235 µg Cu g^{-1} 47 µg Ni g^{-1}	[40]
Lemna gibba	Ur, As	897 µg Ur g^{-1} 1022 µg As g^{-1}	[41]
	Zn	4.23–25.81 mg Zn g^{-1}	[42]
Lemna minor	Ti	221 µg Ti g^{-1}	[43]
	Cu	400 µg Cu g^{-1}	[44]
	Pb	8.62 mg Pb g^{-1}	[45]
Elodea Canadensis	Ni	>3500 µg Ni g^{-1}	[46]
Pistia stratiotes	Hg	0.57 mg Hg g^{-1} 215 ng Hg g^{-1} 83 µg Hg g^{-1}	[47] [35] [48]
	Cr, Cd, Ni	2.50 mg Cr g^{-1} 2.13 mg Cd g^{-1} 1.95 mg Ni g^{-1}	[38]

	Cr, Ni, Zn	> 9 mg Cr g^{-1} > 10 mg Ni g^{-1} > 12 mg Zn g^{-1}	[49]
Egeria densa	Cd, Cu, Zn	70.25 mg Cd g^{-1} 45.43 mg Cu g^{-1} 30.40 mg Zn g^{-1}	[50]
Ceratophyllum demersum	As	525 µg As g^{-1}	[36]
	Cd, Zn	143 µCdg^{-1} 57 µg Zn g^{-1}	[51]
Potamogeton pusillus	Cu	162 µg Cu g^{-1}	[52]
Vallisneria spiralis	Cr, Cd, Ni	2.85 mgCrg^{-1} 2.62 mCdg^{-1} 2.14 mg Ni g^{-1}	[38]
	Hg	158 µg Hg g^{-1}	[53]
Cattails	Se	50 ppm of Se	[54]
Hydrilla	Pb	20ppm of Pb	**[55]**
Azolla	Au	98 mg Au g^{-1}	[56]
	Cd, Cr	1623.201 mg/g Cd and 6013.1 mg/g Cr	[57]
Salvinia	Pb	0.186 mg/g	[58]
Myriophyllum verticillatum	Pb	97.60 mg/g	[59]
Bacopa	Hg, Cd	25.5mg/g Hg, 49.9 mg/g Cd	[60]
Typha aungustifoila	Cr, Zn, Cu	210 µg Cr g^{-1} 325 µg Zn g^{-1} 7,022 µg Cu g^{-1}	[61]

It clearly pointed out that phytoremediation potential of aquatic plants is dependent upon the tolerance level and toxicity of plant genera or species employed in a particular study. Secondly, within a particular plant genus and/or species, there exists a difference in accumulation potential for the same heavy metal. The existing variation is because the phytoremediation potential is regulated by environmental factors like chemical specific and initial concentrations of the metal, temperature, pH, redox potential, salinity, and interaction of different heavy metals among each other. Still a lot of research work is left in area to increase the hyper accumulative capacity of plants.

III. PHYTOREMEDIATION OF TEXTILE DYES

Dye bearing effluents is another major area of concern. Synthetic dyes and pigments are one of major classes of pollutants contributes to industrial pollution. These dyes have a major contribution in the textile industries for dying purpose. As color is a visible pollutant and the presence of even very minute amount of coloring substance makes it undesirable. Discharge of such effluents imparts color to receiving streams and affects its aesthetic value also. The dyes are generally stable to light, oxidizing agents and heat, and their presence in wastewaters offers considerable resistance to their biodegradation and thus get [2] accumulated into aquatic life forms such as fishes. Through the food chain, dyes ultimately posing risks to human beings. Sometimes the products formed after the processing of these dyes themselves are also toxic. In the environment, **Azo** compounds of these dyes are reduced to liberate benzidine and other aromatic amines, which may cause adverse systemic health effects or cancer of urinary bladder cancer, stomach, kidneys, brain, mouth, esophagus, liver, and gall bladder might also be targets [14].Therefore, the removal of Azo-Dyes from industrial effluents is one of the major problems due to the difficulty in treating such waste waters by conventional treatment methods. A very few aquatic species like Eichhornia crassipes, Typhonium flaglliforme,Salivinia, Pistia etc.. have been reported in this area are listed in Table 3:

Table 3: Aquatic macrophytes known for their potential to remediate different dyes

Plants	Dye remediated	Reference
Rheum rabarbarum	Sulfonated anthraquinones	[62]
Phragmites australis	Acid Orange 7	[63]
Blumea malcommi	Direct Red 5B	[64]
Glandularia pulchella	Sulphonated azo dye green HE4B	[65]
Glandularia pulchella	Remazol Orange 3R	[66]
Eichhornia,Pistia, Salvinia	Direct dark blue 6B,Direct black H/Y, Direct congo red	[67]
Typha Angustifolia	Reactive Red 141	[68]
Tagetes patula	Reactive Blue 160	[69]
Cactus	Red HE7B	[70]
Zinnia angustifolia	Remazol Black B	[71]
Algae	Azo dye	[72]
Arabidopsis	Triphenylmethane dyes	[73]
Eichhornia	Red RB and Black B	[74]
Hydrocotyle vulgaris	Basic Red 46	[75]
Typhonium flagilliform	Brilliant Blue R	[76]
Portulaca grandiflora	Reactive Blue 172	[77,78]
Petunia grandiflora	Brilliant Blue G	[79]

The removal of dyes by plant systems can thus provide a new dimension to phytoremediation research. A large number of industries including textile, paper and pulp, printing, iron–steel, electroplating, coke, petroleum, pesticide, paint, solvent, and pharmaceutical etc. consume large volumes of water and organic chemicals which differ in their composition and toxicity. The discharge of effluents from these industrial units to various water bodies leading to water pollution is a matter of great concern, especially for developing countries like India. According to survey carried out by Central Pollution Control Board (2008) [81], ground water in 40 districts from 13 states of India i.e. Andhra Pradesh, Assam, Bihar, Haryana, Himachal Pradesh, Karnataka, Madhya Pradesh, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh, West Bengal, and five blocks of Delhi is contaminated with heavy metals. Also, according to a report published in Times of India (Jan-2013) which clearly states that Punjab among the worst performing state in the country when it comes to checking water-pollution where they dump their toxic waste directly in the river and lake. In India, where most of the developmental activities are still dependent upon water bodies, industrial water pollution is posing serious environmental and health problems. Currently,

$6–8 billion per year is spent for environmental cleanup in the United States, and $25–50 billion per year worldwide [82] and phytoremediation is on an average tenfold cheaper than engineering-based remediation methods Thus, a definite need exists to develop a low cost and eco-friendly technology to remove pollutants thereby improving water quality.

IV. CONCLUSION

Phytoremediation, the use of plants for environmental cleanup, has gained acceptance in the past 10 years as a cost-effective, non-invasive alternative or complementary technology for engineering-based remediation methods. Bioremediation involving the use of microorganisms is a widely studied technology since prokaryotic systems has known to possess diverse metabolic pathways that can metabolize a wide variety of toxicants. But, the fact that plants also comprise of dynamic biological systems that can bestow the plants with excellent remediating abilities was much less realized. Nevertheless, the awareness regarding phytoremediation technologies has been on an increase in the last decade. Industrialization is central to economic development and improved prospects for human wellbeing. But, industrialization has also led to the release of a large number of toxic compounds that have been polluting the ecosystem. Most of the research regarding phytoremediation technologies has focused on the removal of inorganic pollutants like heavy metals and certain types of organic compounds such as polyphenols, chlorinated compounds such as trichloroethylene. But, literature survey has revealed that the remediation of dyes which constitute one group of recalcitrant pollutants is one of the most neglected areas of phytoremediation research. Very few studies have reported the application of these technologies for the removal of textile dyes. These studies lack the screening of different plant species for the removal of textile dyes as that reported for the removal of metal contaminants. Hence, very few potent textile dye removing plant species have been reported. Moreover, there is lot of scope for heavy metal removal also.To which Phytoremediation offers an attractive alternative to remediate industrial pollutants. Hence there is wide scope of research in field of phytoremediation.

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