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Phytoremediation - A Promising Technique in Waste Water Treatment

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Abstract: Water being the source of life has become a scarce resource in this millennium. Since the limited resource availability, reuse of the available supply is more suggestible. For the said goal, many technologies prevail addressing the task, among which is the technique Phytoremediation. Loads of waste waters gets generated from industrial, commercial and domestic origins and is discarded. Phytoremediation converts this waste water into usable water with the help of plants. This is a very ecofriendly technique which decontaminate the waste water in a very economical way. This review article thus emphasizes on this technique process in detail with special emphases on recent studies carried out for Industrial wastewater treatment. The main conclusions arrive at focusing to develop better economic models to handle abundant quantities of wastewater with varied characteristics, overall decontamination efficiency when compared with other conventional techniques.

Keywords: Waste water, Phytoremediation, Ecofriendly.

1. Introduction

Supplying clean and affordable water to fulfill the human needs of the ever-growing population is one of the greatest challenges of the 21st century. In India, the Central Pollution Control Board (CPCB) provides standards with their limiting concentrations for discharge of environmental pollutants from any industry before or after treatment of effluent. In general, a variety of waste water treatment processes are employed which includes primary: physical and physicochemical, secondary: biological process and tertiary. Additionally, the joint treatment of industrial and municipal wastewaters can be economically and environmentally beneficial to both the industry and the municipality.

1.1 *Primary treatment* - Here the suspended solids from the wastewater are separated to some extent. It is a separation process achieved by Screening and sedimentation. After primary treatment effluent, will have high BOD and contains considerable organic material.

1.2 Secondary treatment – Here further treatment of effluent is carried out. Secondary/ Biological processes aim at removal of organic matter and residual suspended solids. After secondary treatment effluent usually has little BOD_5 (30 mg/l as average) and a low suspended solids value (30 mg/l as average). At this stage, most of the biodegradable organic matter is removed but the non-biodegradable or refractory organic material or may be some end products of biological decomposition (synthetic detergents, pesticides, oils, chlorophenols, nitro-compounds, TCE, PCE, PCB etc) on average 40 to 100 mg/l is still present in effluent.

1.3 Tertiary treatment – These are the third or advanced wastewater treatments (AWWT), which are the newer treatment methods been adopted for achieving better quality of water, which aim at removal of toxic and trace elements, reducing health effects and environmental degradation. It is defined as the level of treatment required beyond conventional secondary treatment to remove constituents of concern including nutrients, toxic compounds, and increased amounts of organic material and suspended solids and particularly to kill the pathogenic bacteria [1].

Keeping early WWT objectives same, newer and additional treatment objectives and goals have been added [2], [3]. Further in the present century it is highly essential to develop suitable, inexpensive and rapid wastewater treatment techniques which would enable to reuse water and reduce stress on natural sources. These include (coagulation, filtration, activated carbon adsorption, electro dialysis, reverse osmosis, ozonation, advanced oxidation processes, phytoremediation, zero liquid discharge facility etc.) which are often used for industrial effluents treatment.

2. Advanced Wastewater Treatment Technologies

In WWT plants, treatment systems like microfiltration, ultrafiltration, reverse osmosis, activated carbon adsorption, and sand filters are being employed. For removing particulate matter membrane technologies like micro-filteration and ultra-filtration are being used, for removing dissolved substances nanofilteration and RO, and certain other processes like electrodialysis, carbon adsorbtion, electron beam irradiation, electromagnetic treatment are being considered. Yet another technology for water treatment are Advanced oxidation processes (AOP) which uses combinations of ozone, ultraviolet (UV) light, and hydrogen peroxide that generate highly reactive hydroxyl radical (OH). It ensures the treatment of waste waters that are toxic or resistant to biological treatment [4], [5]. For the treatment of waste water none of the technologies alone can be used or is efficient for exclusion of all pollutants to produce treated effluent that would meet the standards laid by CPCB. A novel and hybrid waste water treatment technology using conventional treatment methods along with AWWT methods appear to be the best. The innovation of advanced technologies for waste water management is highly essential.

Phytoremediation is yet another emerging technology which is a cheap and environmentally cheaper technology for removal of pollutants. Here we review, Phytoremediation with special reference to industrial wastewater treatment. It is novel treatment employed for treatment of domestic wastewater, conservation of soil, sediment and water that would explore in future.

3. Phytoremediation

The combination of two latin words “plant” and “remedy,” gave rise to the term phytoremediation. Phytoremediation is a cheaper and feasible sustainable method for removal of pollutants. At the same time, it is ecofriendly and further it does not affect people living and working in the surrounding as it uses plants for cleaning nature [6]. The plant, plant origin microbes or associated microbiota are used to take up the contamination from soil or water [7]. The remediation is achieved either by retaining, elimination or degradation, by the natural process as it happens in an ecosystem by the involvement of organic or inorganic constituent cycles, thus lead to development of a low-cost remediation technology [8]. Various plant species possess endogenous quality to treat soil, water and air `pollution [9] - [12]. The basic principal behind phytoextraction is the plants ability to accumulate various metals (essential or nonessential).

Phytoremediation of wastewater is an emerging low-cost technique for removal of hazardous metal ions from industrial wastewater and is still in an experimental stage. Heavy metals such as cadmium and lead are not easily absorbed by microorganisms. These toxins when bioaccumulated by natural plant metabolism would prove to be best treatment option. Aquatic plants have excellent capacity to reduce the level of toxic metals, BOD and total solids from the wastewater. It is also an aesthetically pleasing technique that is cost effective, conserves environment insitu. In the present review, we shall discuss about phytoremediation, it’s the major subsets

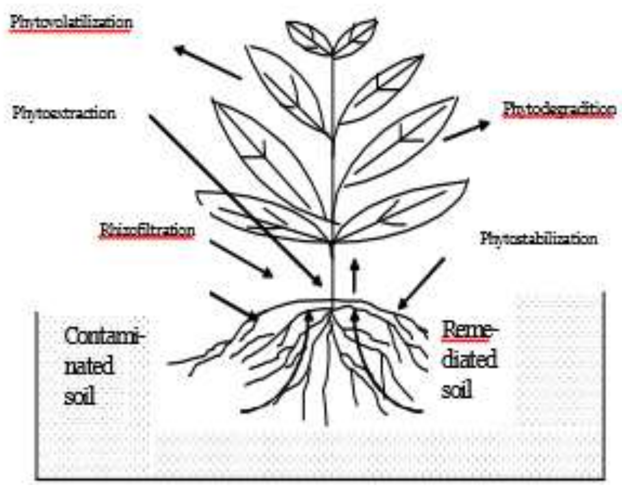
1. Phytoextraction/ phytoaccumulation,
2. Phytodegradation/Phyto -transformation,
3. Rhizofiltration/ Phytofiltration,
4. Rhizodegradation/Phyto -stimulation,
5. *Phytostabilization/ Phytorestoration*,
6. Phytovolat ilization,

followed by a glance of various plants used for phytoremediation of industrial waste water.

3.1 Mechanism of Phytoremediation:

Plant metabolism can help to remediate or clean up contaminated sites. The pollutants enter the plant primarily via the roots, which contains many detoxifying mechanisms, provides surface area for adsorption and accumulation of water and nutrients that promote growth. These pollutants when absorbed by the plant, may be stored in the roots, stems, or leaves; changed into less harmful chemicals within the plant; or changed into gases that are released into the air as the plant transpires [13]. Thus, phytoremediation can take place by any of the following ways viz., as it enters via the root system the pollutant gets stored in harvestable portion in the plant (phytoextraction/phytoaccumulation), get volatized by the plant (phytovolatization), metabolized by the plant (phytodegradation), or any combination of these [14] – [16]. Further the pollutants like heavy metals may sometimes either get adsorbed or absorbed by the plants root system thus aid in remediating the waste streams or aquatic bodies (rhizofiltration) or plants also aid in stabilization of pollutant i.e, reduce its bioavailability rather than cleaning the environment (Phytostabilization). However, the nature of soil, bioavailability and type of pollutants determine the rate of phytoremediation [17]. Fig:1 is a representation of these methods.

Fig 1: Phytoremediation process of contaminated soils: Oh, Kokyo, et al. 2014 [18].



3.1.1. Phytoextraction/ phytoaccumulation

The toxic metal pollutants are absorbed by the plants and then translocated to the above ground biomass like leaves, shoots etc. In this approach, pollutants in the soil are absorbed and get concentrated and then precipitated in the above ground plant body parts. Plants are harvested after the maximum growth of plant and metal accumulations, which indicates remediation of that contaminated site. Thus, this method probably is best suited for phytoremediation of vast area of low to moderately contaminated soils at shallow depths [19], [20]. After remediation, the contaminated plant parts can be harvested, and thus the heavy metals can be recycled [21]. Many plants have the ability of phytoextraction and more than 400 plants have been identified that have the capability to absorb nickel, zinc and copper when compared with other metals. Table 1 – below shows the merits and demerits of phytoextraction.

Table 1: Merits and Demerits of Phytoextraction.

Merits	Demerits
It is inexpensive and permanent phytoremediation of contaminated soils is achieved.	As this method, best suits for shallow depths treatment, bioavailability of contaminants in the rhizosphere is a point of concern
Cost of handling waste disposal is reduced	Plants should be able to grow in high salinity, tolerant to metal/metals content, pH variations
The removed contaminants can be recycled	Rate of metal uptake and translocation to shoot and plants tolerance to metals is essential factor
Growth of plant biomass is limited	Plant must have metal detoxifying capacity
Harvesting and disposal of biomass must be done according to the standards	Hyperaccumulator plant species have slow growth, shallow root system and little biomass
	Presence of metals or other inorganics in soil or sediment

However, the success of phytoextraction for phytoremediation depends on bioavailability of metals, capacity of plant to absorb, concentrate and then either detoxify the metals or produce huge biomass to accumulate more quantity of it and on the level of pollution in the soil. It is further influenced by genetic make and surely by the climatic factors.

Two different strategies of phytoextraction developed are (i) Chelate Assisted Phytoextraction or induced phytoextraction and (ii) Continuous Phytoextraction

(i) Chelate Assisted Phytoextraction or induced phytoextraction: To increase the movement and uptake of metal contaminants artificial chelates (EDTA, HEDTA and EDDNA) are added.

(ii) Continuous Phytoextraction: The inherent quality of plants to secrete chelating agents (phytosideophores) like mugenic and aveinc acids are exploited. These naturals chelants have the tendency to increase the bioavailability of soil bond heavy metals.

3.1.2. Phytodegradation/Phyto-transformation: The organic contaminants present inside and around plant are broken down into simpler molecules by the enzymatic activity of plant and their associated micro-organisms, is called phytodegradation. It occurs by the inherent capacity of plant to release certain enzymes that help to catalyze and degrade pollutants during natural metabolic activity and thus incorporate them into plant body and further promote growth. Its success depends on synergistic associations among plant, microbes, soil and water. The plant provides surface area for microbes to colonize around the root as well as shoot to increase the microbial activity for degrading carbon substrates. Not only enzymatically, mechanically plants also play a key role by reducing runoff facilitating adsorption of compounds on to root surface and promote evapotranspiration.

3.1.3 Rhizofiltration/ Phytofiltration

The plants in phytofiltration are grown water so as to adsorb or absorb contaminants in the water or from aqueous streams rather than in soil, like in phytoextraction. For waste water treatment blastofilteration is considered the second generation of treatment using plants. As the contaminants in wastewater are absorbed either by plant roots (rhizofiltration) or by the seedlings (blastofilteration).

In phytofiltration initially plants are grown hydroponically till large root system develops and later waste streams are introduced for the actual treatment process. Over a period as the plants grow they absorb these contaminants in the root or shoot or both. After saturation, the plants are harvested wholly or only root and then disposed of. Blastofilteration accumulates more number of contaminants than phytofilteration. Rhozofilteration is also effective technology for removals of heavy metals like Cr, Pb and Zn. However, the success of rhizofilteration depends on the metal being removed and on the plants metabolism.

3.1.4 Rhizodegradation/ Phyto-stimulation

The plant root system lodges various microorganisms like bacteria, fungi and yeast which degrade organic matter present in the soil around the roots of plants (called rhizosphere). Micro-organisms break down organic matter, certain toxic compounds, solvents, fuels, that may be sometimes hazardous in nature into simpler compounds for their nutrition and energy. The plant roots release certain compounds which provide food and nutrition for micro-organisms and contribute to the growth and metabolism. These microorganisms in turn consume and digest the organic matter around the rhizosphere into simpler form. This natural process is also called biodegradation.

3.1.5 Phytostabilization/ Phytorestoration: The bioavailability of pollutants is reduced by using plants in this technique. It is achieved by stabilizing the pollutants by plants and thus preventing their dispersion through wind or water. The seepage of pollutants into the ground water table is haulted by regulation of hydraulic motion thus the contaminants get adsorbed onto plant root system or get fixed chemically. The technique of Phytostabilisation is best suitable in fine textured soils with extensively polluted areas and the plants suitable for this type of phytoremediation can be able to with stand high metal concentration, establish easily and grow quickly and should not translocate the pollutants to the consumable aerial parts.

3.1.6 Phytovolatilization

In this type of phytoremediation, the contaminants from the soil are absorbed by the plant roots which are then translocated to the aerial parts and finally to the leaves, where they are transformed during the metabolic activities into volatile form and then are transpired. This method of biomethylation of metals like Hg and Se into volatile form is controversial as it is not known whether the release of volatiles into the atmosphere is safe. In this process plant management is easier as well as it does not require plant

Merits	Demerits
It is a natural process and inexpensive	The rate of remediation is low when compared with the conventional methods
It provides in-situ remediation	Remediation is limited to top layers only
It can conserve soil and water resources	It requires long time period for remediation
Derives energy from sun, and plants are the agents for remediation	Cannot be employed in developed areas where land is expensive
Prevents ground water contamination by controlling seepage	The main limiting factors are the plant, its availability, its ability to grow in contaminated soils and its growth is limited by climate, soil condition and management practices
Improves soil quality, promotes productivity	The rate of remediation varies with plant species as well as the contaminant
Hinders secondary contamination	It is suitable for large contaminated and agricultural sites

disposal. On the whole contaminants that are transpired as well as that those travel from other parts to leaves are involved in process of phytovolatilization. But the probability of these volatiles getting back to the environment cannot be ruled out.

The different phytoremediation techniques discuss above indicate that plants possess inherent quality to treat contaminants. However, there are a few merits and demerits for these processes which are listed in the table 2.

Table 2 –Merits and Demerits of Phytoremediation.

4. Phytoremediation for Wastewater Treatment

It can be achieved by plants either in their natural habitat or by constructed wet lands [22] for treating municipal or industrial wastewater. It is an aesthetically pleasing mechanism that can help for restoration of hundreds and thousands of contaminated sites polluted by anthropogenic source [23], [24]. It is a tremendous, feasible, cost-effective, green technology based on the use of metal-accumulating plants to remove toxic metals, pesticides, explosives including radionuclides from soil and water. It also ensures reduction of remedial costs, restoration of habitat, removal of contamination in its place rather than accumulating it or being transported to another place for treatment. It is successful technology for accumulation of heavy metals; arsenic, lead, mercury, copper, chromium, nickel, Cadmium, Hg, Pb, Zinc, including radionuclide (Sr, Cs and U) from soil, water and air. Most of the organic pollutants including (PAHs) such as benzoapyrene, nitro aromatics such as trinitrotoluene (TNT), and linear halogenated hydrocarbons such as trichloroethylene (TCE) are highly toxic, teratogenic and even carcinogenic, are probable targets of phytoremediation [25].

Phytoremediation by using microorganisms, shrubs to trees for treatment of both domestic and industrial wastewater has been achieved earlier [26], [27].

Many plants have been tested for their bioremediation efficiency by different research groups as alternatives for conventional waste water treatment. Plants such as *Eichhornia crassipes* can facilitate biodegradation of organic pollutants, by accumulating heavy metals like Zn, Cr, Cu, Pb, Ag, and Cd [28], [29]. It can attain exclusion of many varieties of pollutants from wastewater [30]. Billore et al., 2001 [31] carried out the treatment of industrial effluent with the help of plants *Typha latipholia* and *Phragmitis karka*. This treatment eventually led to COD, BOD, total solids and phosphorus content reduction. Some researchers also reported the phytoremediation of phenol from industrial wastewater by peroxidases of tomato hairy root cultures [32].

Many plants have been reported to possess phytoremediation activity; Georgina Wild (Dahlia) can accumulate lead and nickel [33]; *Pterisvittata* accumulates arsenic [34], it can remediate contaminated soils [35] and can absorb Arsenic from water [36]. It has also been used to reduce COD, TSS, TDS and Sulphate [37], while reduction of COD up to 86.6% was achieved by Raj and Anjaneyulu (2005) [38] in pharmaceutical effluent. Plants like Eichhornia *crassipes*, *Pistia stratiotes*, *Nelumbo lutea* and *Marsile aquadrifolia* have been reported to effectively reduce almost all the physical, chemical and biological parameters of the sugar industry effluent water to a significant level [39]. In table 3 below, some of the relevant publications using Phytoremediation technology for treatment of various industrial wastewaters are summarized.

Table 3 - A summary of research studies in which phytoremediation technology were used for treating industry wastewater.

Name of Industrial wastewater used for Phytoremediation	**Plant/Plant part used for Phytoremediation**	**References**	**Concluding remarks**
Removal of toxic hexavalent chromium from mines wastewater, Sukinda mines, Orissa	*Eichhornia crassipes*	Priyanka saha et al., 2017 [40]	This plant could remove 99.5% Cr (VI), from the processed water, TDS, BOD, COD & other elements in 15 days.
Sugar Industrial wastewater	*Eichhornia crassipes, Pistia stratiotes, Nelumbo lutea and Marsilea quadrifolia*	Suggu Sri Gowri Reddy et al., 2015 [41]	All plants efficiently reduced Colour, Temperature, pH, TDS, DO, BOD, COD, Chlorides and Sulphates significantly
Biological Oxygen Treatment (BOT) waste water (Chloride, sulphate, BOD, COD, TDS) of coke oven plant	*Lemna minor*	Priyanka saha et al., 2015 [42]	It removed 30% chloride, 16% sulphate and 14% TDS.
Treatment of effluents from 3 seleted FOOD AND BEVERAGES industries IN GHANA	*Vertiveria zizanioides*	Yeboah SA et al., 2015 [43]	Best contaminants removal was found in Biogas effluent, followed by effluent from Pinora effluent. While Oil Palm industry experienced lowest removal of contaminant
Bioremediation of heavy metals like Cd, Cr, Cu, Zn, Fe & B in ceramic industry wastewater	*Water hyacinth*	Elias, Siti Hanna, et al. 2014 [44]	Heavy metal removal upto 70% was attained, which followed the order Fe>Zn>Cd>Cu>Cr>B during the treatment process
Treatment of industrial wastewater with a high concentration of NO3, nitroglycerin, and nitroglycol	*Acorus calamus (sweet flag), Phragmites communis (Common reed),* *Typha latifolia* *(broadleaf cattail)*	Roman Marecik et al., 2013 [45]	It was observed that the application of sweet flag and common reed contributed to a high nitrate removal efficiency (82 and 79%, accordingly). Sweet flag also was most efficient for decontamination of nitroglycerin (87%) and nitroglycol (42%). While the performance of broadleaf cattail was lower.
Reduction of heavy metals (Cd, Cr, Pb) from wastewater of sugar mills of Layyh	*Euphorbia Prostrata*	Amjad Husnain et al., 2013 [46]	Results indicate this plant as a promising plant for both phyto-remediation and biosorption of heavy metals.
Comparitive assessment of 4 different plants to treat heavy metals from industrial effluents	*Typha latifolia, Eichhornia crassipes, Salvinia molesta, Pistia stratiotes*	Dipu sukumaram 2013 [47]	All plants showed varied responses to different effluents.

Treatment of paper mill effluent along with removal of heavy metals JK Paper mill, Rayagada, Orissa	*Eichhornia crassipes, Hydrilla verticillata, Jussiaea repens, Lemna minor, Pistia stratiotes and Trapa natans*	Mishra S et al., 2013 [48]	Results showed significant decrease in pH, conductivity, TDS, TSS, chlorine, sulphur, BOD & COD. And also, Hg was reduced to 66.5 % by L. minor followed by T. natans (64.8 %). L. minor reduced Cu by 71.4 % followed by E. crassipes (63.6 %).
Swine industry wastewater containing heavy metals Zn, Cu	*Typha domingensis Pers. and Eleocharis cellulose*	Cortes-Esquivel, Jorge A., et al., 2012 [49]	Both plants efficiently phytoremediated Zn & Cu
Removal of heavy metals from Industrial effluent	*Eichhornia crassipes*	H. E.Hassan et al., 2012 [50]	Results indicate that 50 % of studied metals were removed within 1hr. (Cu, Pb, Zn, Cr and Ni), 26 % within 9hr (Mn and Ba), 10% in 6hr (Cd) and 10% in 24 hr (Fe).
To treat textile, metallurgical, and pharmaceutical wastewaters (BOD, DO, TSS, nitrate-nitrogen and Cd, Cu & Fe)	*Eichhornia Crassipes*	T O. Ajayi et al., 2012 [51]	The assessed parameters were significantly reduced in the pharmaceutical wastewater followed by the metallurgical wastewater and lastly the textile wastewater. It also removed Cd efficiently but least efficient for removing Cu & Fe.
Comparitive assessment to treat Diary effluents.	*Typha sp., Eichhornia sp., Salvinia sp., Pistia sp., Azolla sp., Lemna sp*	S. Dipu et al., 2011 [52]	*Typha* sp.-based constructed wetland has proved as a promising technology for dairy effluent
Removal of heavy metals (Al, Fe, Zn, Pb) from industrial effluent, soil & sediment. El-Sadat city, Egypt	*Typha domingensis*	A. K. Hegazy et al., 2011 [53]	Typha domingensis was capable of accumulating the heavy metal ions preferentially from wastewater than from sediments
Wastewater from Kaliapani chromite mine region, Orissa	*Oryza sativa L. cv. Khandagiri*	Mohanty M et al., 2011[54]	70% to 90% reduction of Cr+6 levels was observed in irrigated mine wastewater
Chromium mine waste water treatment	*Eichhornia crassipes*	Mohanty M. and H.K. Patra, 2011 [55]	54% reduction of Cr+6 was observed from contaminated mine waste water
Singrauli, an industrial region, India (effluent from three industries were assessed for Hg & Cd phytoremediation	*Azolla pinnata*	Rai, Prabhat Kumar., 2008 [56]	The results indicate that this fern has tremendous potential to accumulate heavy metals and thus can be used efficiently as bio accumulator
Textile process effluent	*Eichhornia crassipes*	B.V. Kulkarni et al., 2007 [57]	Effective reduction of COD and Metals
Textile waste water	*Eichhornia crassipes*	Mahmood, Q et al., 2005[58]	Efficiently reduced pH, COD, BOD, TSS, TDS, & heavy metals like Cr, Zn, Cu present in textile effluent
Pulp and paper mill and distillery effluent (pH, EC, BOD, COD, TSS, TS, TDS, colour, lignin, Na and K)	*Vallisneria spiralis (Channel Grass)*	Singhal, V et al., 2003 [59]	Except for pH all other parameters are effectively reduced

5. Conclusion

From these few success studies mentioned above, it could be concluded that, Phytoremediation is a yet another emerging technology with good efficiency for treating effluents and should be encouraged, so that it can be applied practically so that water and soil resources can be restored in situ. It is green technology which uses plants for remediation and thus would prove to be a safe technology for restoring environment. Compared to the expensive conventional techniques solar driven Phytoremediation is ecologically a better and promising choice with bright future. Efforts should be focused on exploring and utilizing this technology to get treated water meeting the standards and thus conserve the environment aiming at sustainable development and reduce stress on natural resources.

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