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A review on phyto-remediation by aquatic macrophytes: A natural promising tool for sustainable management of ecosystem

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Abstract: Heavy metal pollution is a significant source of pollution in the environment. Heavy metal contamination in aquifers endangers public health and the freshwater and marine ecosystems. Traditional wastewater treatment methods are mainly expensive, ecologically damaging, ineffective, and take much time. Phyto-remediation is a plant-based technique that gained popularity by discovering heavy metal accumulating plants that can accumulate, transport, and consolidate enormous quantities of certain hazardous contaminants. This is a low-cost sustainable evolving technique featuring long-term utility. Several terrestrial and aquatic vegetation have now been examined for their ability to repair polluted soils and streams. Several submerged plants have already been discovered to remove harmful pollutants such as Zn, As, Cu, Cd, Cr, Pb & Hg. The most important part of effective phyto-remediation is selecting and choosing effective plant species. Aquatic macrophytes have high effectiveness for removing chemical contaminates. Watercress, hydrilla, alligator weed, pennywort, duckweed plants, water hyacinth are examples of aquatic macrophytes. Several macrophytes' metal absorption capability and procedures have now been explored or analyzed. Most of these research demonstrated that macrophytes had bioremediation capability. The bioremediation capability of macrophytes can be increased even more by employing novel bioremediation techniques. To demonstrate the extensive application of phyto-remediation, a comprehensive summary assessment of the usage of macrophytes for phyto-remediation is compiled.

Introduction

Water pollution, alongside restricted freshwater or drinking-water supply, has imposed a significant load on the ecosystem. Shortage of water affects approximately 40 percent of overall worldwide people due to global warming, fast urbanisation, agricultural production, and unrestrained resource exploitation (Calzadilla et al., 2010; Connell, 2018). Rapid urbanisation, industry, farming activities, outflow of groundwater increased the flow of contaminated wastewaters and sewage into the environment over the last few years (Aguilar, 2009; Rahman and Hasegawa, 2011; Renuka et al., 2013; Goncalves et al., 2017). Wastewater with high quantities of contaminants is hazardous to freshwater and marine water ecosystems and public health (Ahmed et al., 2017; Carstea et al., 2016; Mendoza et al., 2015). Effluent recycling is the only alternative available to meet the growing need for water in agriculture's developing areas (Tee et al., 2016).

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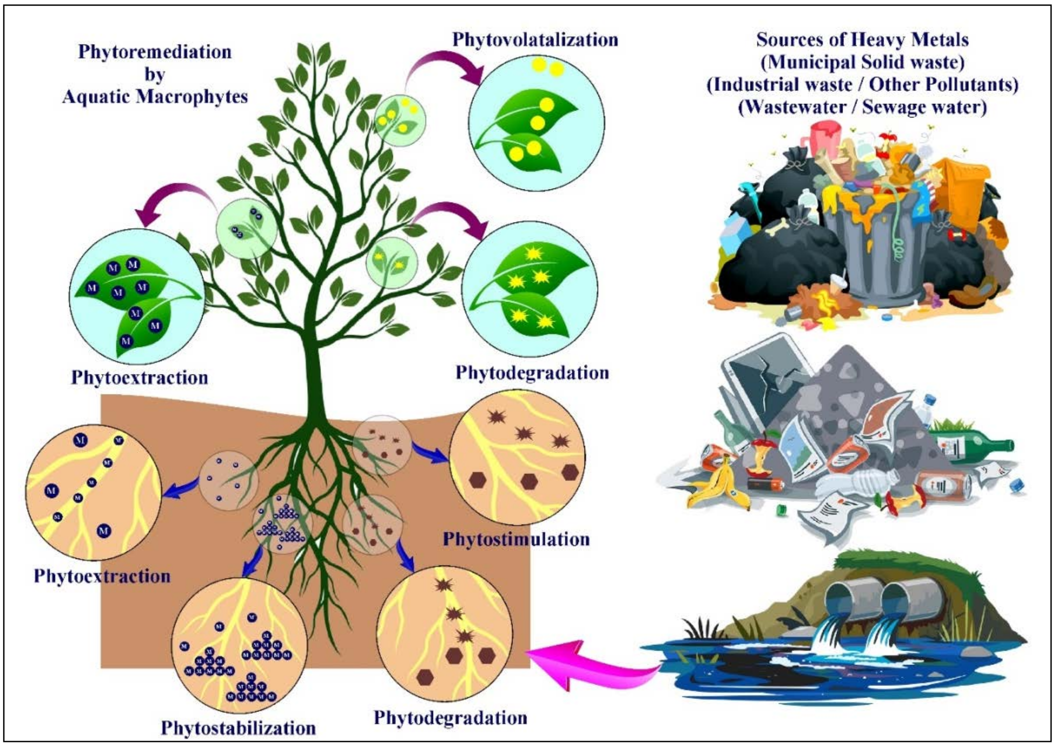

Figure 1. Graphical representation of Phyto-remediation by Aquatic Macrophytes.

Agrochemicals, lubricants, colours, polyphenols, dithiocarbamates, hazardous organic pollutants, phosphorus, large particles, and heavy metal ions are all found in unprocessed household and commercial effluent (Mohammadzadeh Pakdel and Peighambardoust, 2018). Heavy metals, for example, Pb, Hg, Cd, Cr are quickly deposited throughout the outdoor landscape (An et al., 2015). Metallic industry, mineral extraction, geothermal electricity stations, automobile, pulp, insecticide production, dyeing, colouring, and electroplating are all blamed for worldwide metal toxicity (Peligro et al., 2016; Raval et al., 2016). Heavy metal elimination from sewage is challenging due to the fact that they occur in many chemical components. Several elements really are not biodegradable, and so they can readily transit across multiple tiers, accumulating in the biosphere indefinitely (Gall et al., 2015; Zhu et al., 2016). Hazardous contaminant elimination is critical in order to reduce the harm to public health and the environment.

Water pollution from natural and inorganic chemical contaminants is a major problem. Pollutants are generally difficult to eliminate naturally, while they may be converted from incredibly poisonous to lower harmful forms (Jiang et al., 2018, Zhang et al., 2017). As a consequence of the increasing population, industrialisation, urbanisation, and excessive use of freshwater, groundwater and supply water as well as river water, are deteriorating (CDC, 2016; Ebere Enyoh and Wirnkor Verla, 2018; WHO, 2006). Polluted water bodies disrupt whole freshwater systems, affecting the lives of animals, vegetation and even of microbes. Environmental degradation really harms both the individual and also community levels of freshwater ecosystems. Water-body is contaminated mostly by fertilisers, office and medical & domestic and municipal effluent, toxic substances, insecticides, petroleum, as well as a variety of other natural and various toxic inorganic substances (Verla et al., 2018).

Nutrient enrichment of the aquatic system came about as a consequence of molecular and ionic compounds of N & P (Khan and Ansari, 2005). Aquatic ecosystem degradation is indeed a serious, harmful, and global issue that has been currently unregulated due to the absence of knowledge, consciousness, as well as rigorous execution of environment-friendly laws, regulations & economic ability (Akpor and Muchie, 2010; Eid et al., 2020). Heavy metals are known to be worthwhile issues of cutaneous illnesses, asthmatic problems, cancers, fatigue, breathing illnesses, cardiac and urinary tract issues, and stunted adult neurogenesis. In living creatures, Cadmium affects and disrupts the cellular membrane. Chromium is a serious carcinogenic element, as well as its interaction with life forms, produces a variety of negative health effects (WHO, 1984).

Heavy metal elimination procedures, including RO, electrodialysis, coagulation/flocculation, desorption, and solvent evaporation, are expensive and typically not ecologically beneficial. Such traditional heavy metal clearance or elimination approaches are often expensive and complex (Al-Alawy and Salih, 2017; Levchuk et al., 2018; Huang et al., 2017; Burakov et al., 2018, Kulkarni

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et al., 2018; Olguin and Sanchen-Galvan, 2012). Such treatment processes necessitate a significant financial investment as well as, in the meantime, create the issue of sludge & wastewater discharge into the environment (Grandelement et al., 2017). Ecologically acceptable & cost-effective processing technique is required for such recovery of effluent contaminated with toxic substances & pollutants (Gonzalez-Gonzalez et al., 2014; Shahid et al., 2018). The present study demonstrates an environmentally acceptable strategy for pollutant removal called phyto-remediation. Moreover, this literature review discusses the possible use of macrophytes in bioremediation for treating sewage & waste water.

Heavy metals found in aquatic system

Heavy-metal contamination is mostly caused by human as well as geophysical activity. Metallic pollutants are produced by the process of raw material sourcing, combat activities, waste materials, fertilisation, urban sewage outflow, car exhaust pipes, sewerage, incinerators, fuels generation, and casting (Hargreaves et al., 2018; Zhong et al., 2012). Corrosion, degradation of stones, as well as volcanic activities are all underlying factors of metal contamination. The main and first primary occurrence of toxic substances involves parent material through degradation (Hasballah and Beheary, 2016).

Farming insecticides & fertiliser use on surface soils has increased Zinc, Copper, Cadmium and Arsenic concentrations in soils (Zarcinas et al., 2004). The ever-increasing agricultural production has boosted the use of insecticides, fertilisers, & chemicals. Inappropriate use of such herbicides and pesticides might lead to the build-up of such toxins in crops (Khairiah et al., 2006). The use of phosphate fertiliser and synthetic fertilizers to manage plant pathogens results in an unequal amount of Nickel, Lead, Zinc, Cadmium, & Chromium (Nagajyoti et al., 2010). The tremendous amount of fertiliser is used to give Phosphate, Nitrogen, Potassium into vegetation for boosting development, which increases arsenic, Pb, Hg & Fe in significant-high quantities. Heavy metal (HM) additions into farmland from increased chemical fertiliser use raise concerns regarding its potential environmental harm (Czarnecki and During, 2015, Kamran et al., 2013).

Discharge of untreated water into agricultural land promotes the accumulation of HMs such as Cd, Pb, Ni& Zn. These kinds of elements, such as Zinc, Copper, Nickel, Cadmium, & Lead, are commonly found inside the subsoil of land that has been watered using wastewater discharges. Long-term irrigation using untreated effluent or water raises the overall amount of heavy metals in the soil to hazardous levels (Paul, 2017). A major cause of topsoil pollution loads seems to be the uncontrolled disposal of sewage sludge. Open dumping and illegal dumping are prevalent methods of disposing of domestic & clinical garbage across the globe. Although becoming a valuable source of nutrients, those pollutants also contain various dangerous poisonous elements. Fertiliser, insecticide, and herbicide treatments that are hazardous or excessive are major contributors to metal contamination (Islam et al., 2018). Shipping could also lead to metal toxicity. Infrastructure repair and cooling or defrosting procedures create underground water pollution. Erosion, tire damage, and braking friction are all well-documented sources of contamination associated with expressways (Sanchez-Martin et al., 2000).

Phyto-remediation

Phyto-remediation is regarded as a useful, efficient, visually beautiful, cost-effective, and environmentally benign method of removing various harmful elements from the environment. The plant used in bioremediation acquires toxins via the root and transports them to the soil surface area of its structure (Ashraf et al., 2018; Sharma et al., 2014). The concept of employing metals aggregator plants in bioremediation to remove toxic substances as well as other toxins was initially presented in 1983, but now it has been established for the previous three hundred years (Vangrosveld et al., 2009; Sarwar et al., 2017; Kushwaha et al., 2018).

The incorporation of plants, soils, & microorganisms, and other ecological techniques, renders biological decontamination a highly enticing ecological solution for such buildup of various pollutants (Helmisaari et al., 2007; Mahar et al., 2016). On-site treatment is much more widely employed since it decreases the proliferation of pollutants in wastewater and aerial wastes, lowering the surroundings' danger (Raskin and Ensley, 1999). Phytoremediation may treat many types of contaminants onsite, eliminating the requirement for a dumping location. This also prevents pollution from spreading by limiting land degradation and infiltration (Sun et al., 2011). The clean-up expense of phytoremediation is significantly lower than that of other traditional remediation approaches, which is its primary benefit (Gerhardt et al., 2017). Phytoremediation is indeed a reasonably simple procedure because it doesn't need the use of specialised individuals or technology. This seems appropriate for wide area cleanup whether other traditional procedures proved to be exceedingly expensive and ineffective (Oyuela et al., 2017).Pesticides, trichloroethylene, aromatic compounds, Polychlorinated chloro-benzene, radio nucleo-bases, lubricants, combustible materials, and toxic metals are just a few toxins that phyto-remediation technique may remove (Hussain et al., 2018; Bennett et al., 2003). A variety of vegetation types may collect a much larger amount of heavy metals in various areas of the body parts without being hazardous (Reeves et al., 2017).

Mechanism of phyto-remediation

Plants have the ability to absorb, eliminate, change, and repair contaminants. Plants have the potential to clean up polluted environments (Hettiarachechi et al., 2012). Plants remove pollutants from polluted places in various ways (Prasad et al., 2003). Typically, such plants store contaminants without disrupting the subsoil, preserving overall quality as well as texture. Those plants promote agricultural productivity by providing organic matter and nutrients to the soil.

Many plants remove hazardous chemicals from the earth whilst growing roots absorb moisture and minerals from filthy soils, sediments, and subterranean water. Plants may cleanse toxins by using natural mechanisms by storing the heavy metals or contaminants in the plant body parts such as leaf, stem, root etc. As far as the root systems can reach, hazardous materials are converted into vapours and dispersed into the environment. Plants transform deposited contaminants into less hazardous compounds in their root system. Plants generally have a tremendous potential to absorb pollutants from the environment and detoxify them via several methods. If the polluted plants are let to deteriorate; the toxins will be released into the soil. To completely remove contaminants from such a region, the vegetation should be chopped down and removed in a lesser harmful manner. The time duration, diversity of species needed, & species types are all determined by the site parameters and, most importantly, the kind of pollutant. The first most important things to consider when applying bioremediation to a region are the type of pollutants, living organisms, and degrees of pollution and pollutants (Hettiarachechi et al., 2012).

Types of phyto-remediation

Phyto-remediation employs many methods such as Phyto-extraction, Phyto-stabilization, Phyto-volatilization, Rhizo-filtration or Rhizo-degradation, Phyto-transformation and Phyto-filtration during heavy metal absorption or aggregation in the plants (Sarwar et al., 2017). The various processes involved in phyto-remediation are described briefly here.

Phyto-extraction

Phyto-extraction, commonly known as phyto-accumulation, is the process by which heavy metals are absorbed in root system and subsequently translocated to an aerial component of a plants such as buds, leaves, etc. After phyto-extraction, plants may be gathered and burnt to produce energy as well as, if necessary, recover/recycle metals from the ashes (Erakhrumen, 2007; Chandra et al., 2018). Phyto-remediation and phyto-extraction are often used interchangeably, and this is misleading, phyto-extraction is a cleaning procedure but phyto-remediation seems to be the title of a principle (Prasad et al., 2005). Phyto-extraction is an effective phyto-remediation technology enabling the adsorption of

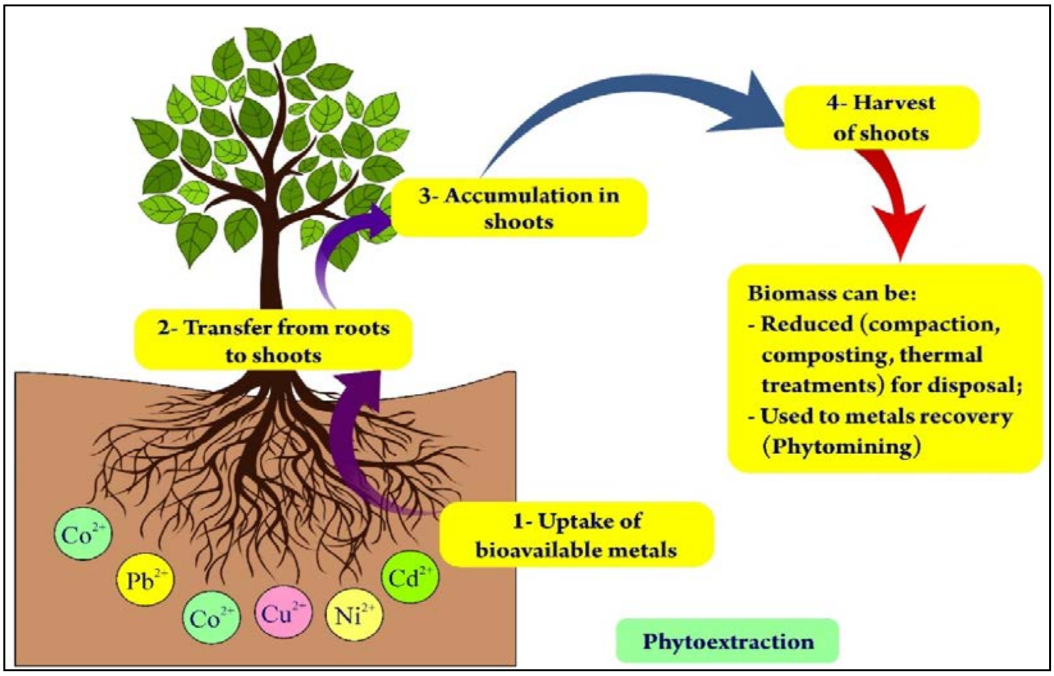

Figure 2. Mechanism of Phyto-extraction.

heavy metals, sedimentation, and topsoil (Kocon and Jurga, 2017; Ali et al., 2013).

Mechanism

Contaminants are absorbed by the plant's roots and accumulated inside the root systems or carried into above-ground sections of the plant (Fig. 2). The plant can repeat such a technique until it has been eliminated. Because a tiny quantity of the contaminants remains inside the land after cleanup, such development and withdrawal should be performed on a frequent basis over a range of plants to achieve significant cleanup. Following this operation, the cleaned soil can support additional crops. The number of days required for elimination is determined first by the kind and quantity of metal contamination, the overall duration of the planting season, as well as the efficacy of metal exclusions by vegetation (Blaylock and Huang, 2000).

Advantages & Disadvantages

This method is suitable for detoxifying of land with small to moderate pollution levels. Vegetation is really not possible on heavily polluted grounds. Metals in the soil must also be accessible and capable of being absorbed by the root system. The combination of these two qualities, including such high heavy metal deposition and rapid photosynthetic activity, results in maximal removal of heavy metal ions (Blaylock and Huang, 2000).

Phyto-stabilization

Phyto-stabilization uses plants to limit the migration of pollutants in soil. Phyto-stabilization is often referred to as in-situ inactivation of contaminants. This method may be used to successfully remediate land, sewage, & sediments. It has no negative effects on ecosystems which is a much better acceptable alternative (Cundy et al., 2013; Najeeb et al., 2017; Jadia and Fulekar, 2009). Plants restrict or function as just a shield to fluid infiltration inside the ground during phyto-stabilization. When we really need to persist in our fresh water, underground aquifers, or soil health recovery, this technique is suitable for the job since it stops the passage of pollutants (Jadia and Fulelkar, 2009; Labidi et al., 2017). Phyto-stabilization is quite beneficial for a broad site that has been highly contaminated (Mahdavian et al., 2015). Phyto-stabilization is merely a management strategy for deactivating potentially hazardous pollutants. This is not a long term solution since only metal transportation is controlled, but metal remain inside the ground (Zeng et al., 2018).

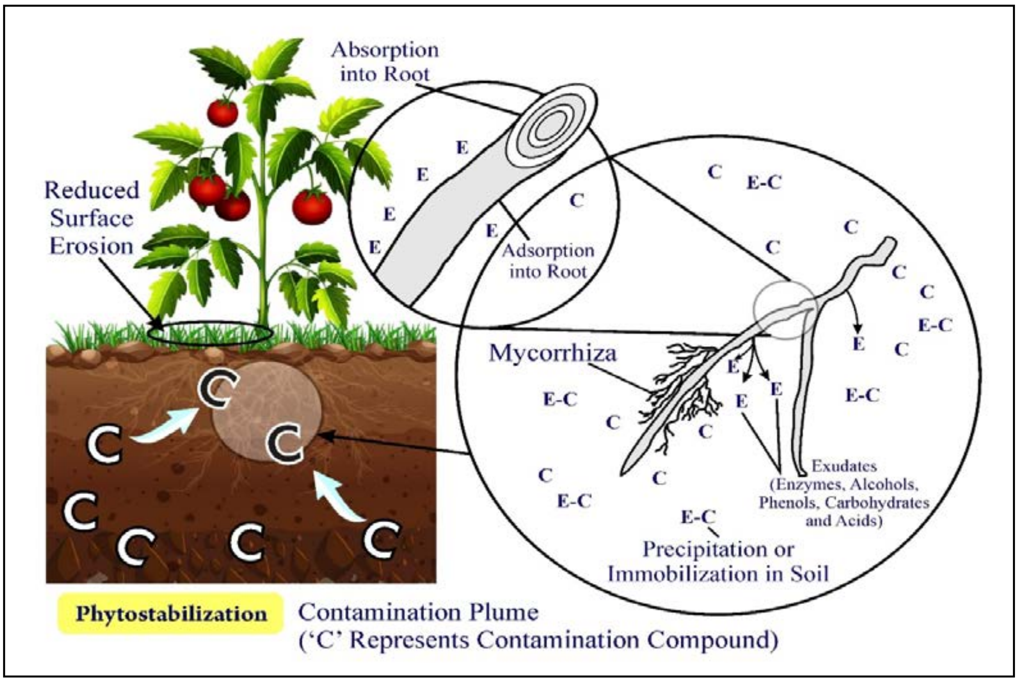

Figure 3. Mechanism of Phyto-stabilization.

Mechanism

This method reduces the flow of contaminants, allowing particles to be relocated to subsurface waterways. This technology could also regenerate plant growth in areas where normal plantations have died because of too much metal concentrations in overlying grounds or the physiological fragility of surface components. Metal-tolerant plants are utilised to restore the plants in contaminated places. As a result, there'll be low opportunities for contaminant transmission in groundwater caused by wind eroding and bare ground surfaces. This method is being used to remove Pb, Zn, As, Cd, Cu, Cr etc (Etim, 2012).

Advantages & Disadvantages

Phyto-stabilization offers several benefits over all other cleanup approaches since it is inexpensive, environmentally benign, simple to administer or even use, & adds cosmetic appeal (Jabeen et al., 2009). It is particularly effective in locations containing homogeneous soil rich in organic compounds, although it is also excellent for treating a wide range of areas with significant water contamination. Plant survival is not viable in extremely contaminated areas. Hence phyto-stabilization is indeed not conceivable (Suman et al., 2018).

Rhizo-filtration

Rhizo-filtration is the employment of plants to absorb/adsorb pollutants, leading to the pollutants' mobility being limited in groundwater sources (Abhilash et al., 2009; Benavides et al., 2018). Roots have a critical role in rhizo-filtration. The accumulation of toxic substances just on surfaces of roots is aided by variables, including such fluctuating pH in the rhizosphere as well as roots secretions. When plants have absorbed all toxins, they may be readily collected and discarded (Zhu et al., 1999). Crops for rhizo-filtration must produce vast rhizomes, accumulate large amounts of heavy metals, be simple to manage, and require little care (Raskin et al., 2000). Vegetation with extensive fibrous roots, freshwater and land macrophytes could be employed in rhizo-filtration (Raskin et al., 2000).

Rhizo-filtration may be utilised to effectively handle and purify wastewater discharges, industrial emissions, nuclear contaminants, and minerals (Galal et al., 2018). Heavy metal ions primarily maintained inside the land, including Cd, Pb, Cr, Ni, Zn, Cu, could be effectively decontaminated via rhizo-filtration (Sreelal and Jayanthi 2017).

Mechanism

Plant roots emit certain substances within the rhizosphere region, resulting in biochemical processes that aggregate pollutants onto roots and into the aquatic environment. Whenever the roots get saturated with contaminants, the roots or entire plants are simply chopped off and discarded (Rawat et al., 2012).

Advantages & Disadvantages

Rhizo-filtration is a less expensive technology used to remove significant concentrations of heavy metals (Cr, Pb, Zn) in aquifers. However, the goal of this technique is much more hard to reach and much more prone to failure than some other approaches of comparable cost. Developing and preserving hydroponic systems necessitates the use of qualified and knowledgeable labour. The need for expertise and advanced machinery might raise operational expenses (Ensley, 2000).

Phyto-volatilization

Phyto-volatilization is indeed the procedure through which a plant transforms contaminants towards a more volatile form and subsequently releases them further into its surroundings via the plant's pores (Ghosh and Singh, 2005). Plants such as *Brassica napus*, *Brassica juncea* can help in phyto-volatilization of selenium. Hg & Se are by far the most promising pollutants for phyto-volatilization remediation (Karami and Shamsuddin, 2010). One of the huge benefits of phyto-volatilization is that it doesn't need any extra maintenance after the cultivation is completed. Additional advantages include less land degradation, minimal ground disruption, unfulfilled harvesting, as well as the removal of crop residues (Cristaldi et al., 2017). Micro-organisms in the root system also aid in the bioconversion of the pollutant, increasing the speed of phyto-volatilization.

Mechanism

The procedure through which contaminants are absorbed by plants and then transpired is known as phyto-volatilization. Simultaneously, the plant emits a contaminant or a modified version of a contaminant into the environment. Phyto-degradation is a connected phyto-remediation mechanism which can happen in conjunction with phyto-volatilization (Rugh et al., 2000).

Advantages & Disadvantages

Areas that apply such phyto-volatilization process might not even require significant care only after crops are planted. But that kind of decontamination offers other benefits, such as the fact that all these sites were much less disturbed, there is less possibility of runoff, as well as the vegetation employed in this procedure does not have to be thrown away. Phyto-volatilization would not have been appropriate in areas near densely inhabited areas or in areas with specific weather systems that favour the rapid settling of volatile chemicals (Rugh et al., 2000). In contrast to conventional treatment methods, if contaminants are eliminated by phyto-volatilization, there'll be less influence on subsequent migration to certain other locations. The usage of this procedure is limited since contaminants are not totally removed but merely change their location, like shifting from one part of the

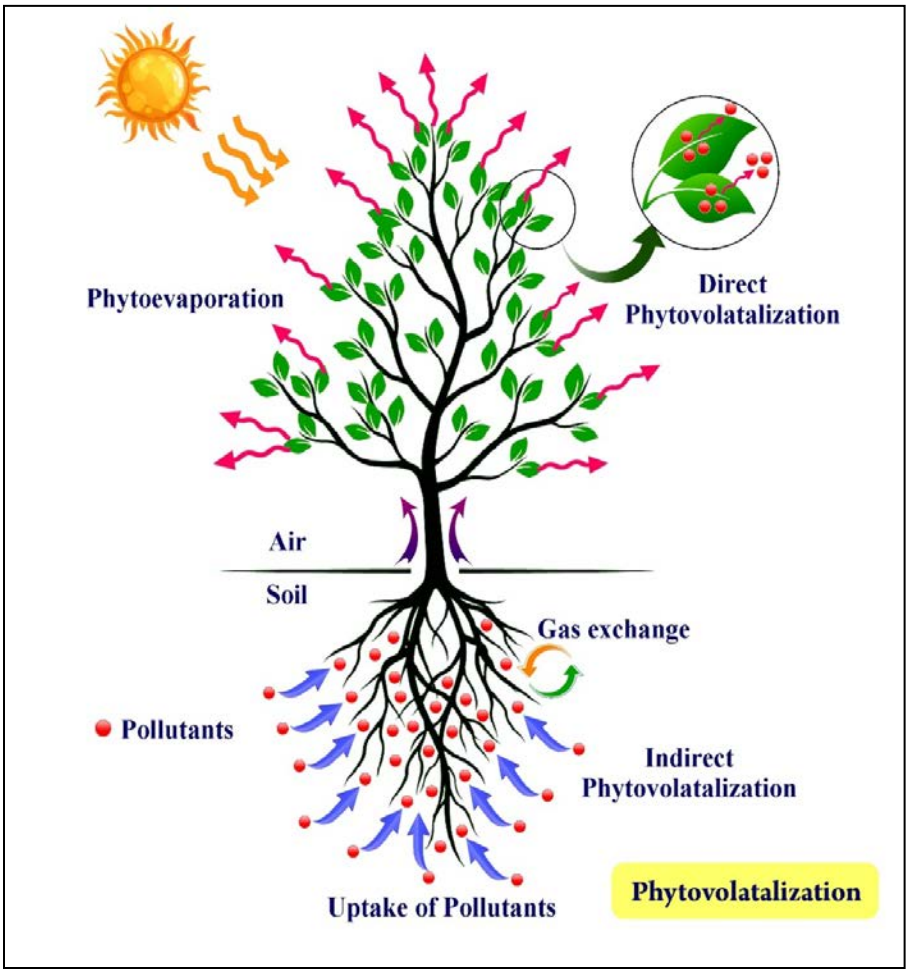

Figure 4. Mechanism of Phyto-volatilization.

ecosystem (land) towards another part (air) and then eventually deposited somewhere else. Phyto-volatilization is the most disputed phyto-remediation process (Padmavathiamma and Li, 2007).

Phyto-transformation

The absorption of biological or nutritional pollutants from the ground and water is referred to as phyto-transformation. It is also known as phyto-degradation. Phyto-transformation can be used on industrial sites as well as other locations for cropland pesticides, munitions pollutants, halogenated hydrocarbons, gasoline spillages, and industrial effluents etc (Schnoor, 1996).

Phyto-stimulation

Phyto-stimulation, also known as improved rhizosphere biodegradation, is indeed the biological decomposition of organic pollutants in the ground by increased soil microorganisms in the root zone of the plants or rhizosphere. This technique may be used to clean up herbicide-contaminated areas. Plants having a high potential to increase soil microbial activity must be chosen (Souto et al., 2020).

Microorganism interaction in the rhizosphere is induced across several different manners: (1) substances secreted by the root system, including such carbohydrates, simple sugars, micronutrients, carboxylates, and metabolites, augment indigenous beneficial microorganisms; (2) rhizomes bring oxygen towards the rhizosphere, ensuring aerobic transformations; (3) fine-root organic matter improves accessible carbon source; as well as (4) mycorrhizal fungi, something that develops inside the root system, could indeed deteriorate organic pollutants that could be converted by some bacteria due to their unique metabolic pathways (Anderson et al., 1993). This approach is excellent for eliminating organic pollutants from surface soils, like insecticides, aromatics, and heterocyclic aromatic compounds (Marryott, 1996).

Toxic element phyto-remediation by aquatic macrophytes

Both fresh water and marine reserves are now being affected by numerous harmful materials as a result of man-made and natural causes. As a result, recovery of damaged aquatic ecosystem is just as vital as bioremediation of polluted terrestrial environments. Because the

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procedure includes an adsorption process and biomagnification of the dissolved and accessible pollutants from wastewater, freshwater habitats, or even other drifting vegetation may successfully accomplish bioremediation of harmful pollutants (Marryott, 1996). Macrophytes in aquatic phyto-remediation techniques could either be drifting just on the surface of the sea or immersed in it. The root of drifting aquatic metal-accumulating vegetation receive or store pollutants, whereas the entire body of submerged macrophytes accumulates metals.

Many aquatic macrophytes as well as other tiny aquatic drifting plants, have already been studied for their potential use during the treatment of raw and sewerage polluted with Copper and Mercury (Sen and Mondal, 1987; Selvapathy and Sreedhar, 1991; Alam et al., 1995). Lead and Nickel cleanup have been investigated using Lemna minor (Axtell, 2003). Aluminium phyto-extraction was evaluated on four major aquatic species of plants (*Sparganium angustifolium*, *Typha latifolia*, *Potamogetonepihydrus* and *Sparganium multipedunculatum*) (Gallon et al., 2004). *Mentha aquatica, Ludwigina palustris* as well as *Myriophyllum aquaticum* have all been shown to successfully eliminate Iron, Zinc, Copper, and Mercury from raw sewage (Kamal, 2004).

It has been found that *L. minor* accumulates Copper and Cadmium from polluted effluent (Kara, 2004; Hou et al., 2007). *Myriophyllum spicatum* has now been identified as an effective species of plant for sewage effluent treatment (Lesage et al., 2007; Robinson et al., 2006). Copper from polluted waterways is accumulated by the macrophytes, *Rorippa nasturtium aquaticum* (Pratas et al., 2014). The favourable findings of earlier research on phyto-remediation utilising aquatic vegetation attracted the interest of academics and experts, prompting them to pursue more study in this area.

Aquatic plants & phyto-remediation

Aquatic macrophytes can also be referred to as aquatic plants. Cyanobacteria, Pteridophyta, Bryophyta, Rhodophyta, Spermatophyta, Chlorophyta, Xanthophyta are the seven plant subdivisions or categories. Macrophytes are classified into four primary classes based on their growth patterns, which are as follows:

Category I is often referred to as emerging macrophytes. These are all the species that have roots inside the ground and therefore are growing to significant elevations just above the waterline. Such plants include *Typha latifolia*, *Phragmites australis* etc (Lesiv et al., 2020).

Category II is sometimes known as drifting macrophytes. This category of plants, which comprises angiosperm trees, is typically found on wet substrates in shallow waters. *Potamogeton pectinatus* is an example of one of them (Lesiv et al., 2020).

Category III includes submerged macrophytes. These are typically found just under the surface of the water. Mosses, angiosperms and pteridophytes are all members of this group (Lesiv et al., 2020).

Category IV includes Free-drifting plants. All of those are rocky surface vegetation that is not anchored. This group's surroundings and features are quite diverse (Lesiv et al., 2020).

An aquatic environment seems to be a cost-effective as well as efficient phyto-remediation technology for a vast damaged region. Macrophytes function as efficient absorbers of pollutants and toxic substances (Pratas et al., 2014). Most efficient and lucrative approach for removing harmful pollutants as well as other toxins is to use aquatic vegetation (Ali et al., 2013; Guittonny-Philippe et al., 2015). Wetlands, together with aquatic vegetation, have been widely used for sewage treatment across the globe (Gorito et al., 2017; Mesa et al., 2015). The identification of aquatic vegetation types for heavy metal accumulation is critical for improving phyto-remediation (Galal et al., 2018; Fritioff and Greger, 2003).

Macrophytes have built an enviable strong reputation for the ability to wipe up polluted places all around the globe (Gorito et al., 2017; Gopal, 2003). Macrophytes, generally grow large rhizomes that aid growth and provide them with the ideal alternative for pollutant build up in both shoots and roots (Mays and Edwards, 2001; Stoltz and Greger, 2002). Macrophytes development and culture take a lot of time, which might also limit the rising need for phyto-remediation (Said et al., 2015). Nonetheless, this weakness is compensated for through significant advantages that this method has towards sewage treatment (Kozminska et al., 2018; Syukor et al., 2014). The ability of several macrophytes to attenuate various heavy metals is listed in Table 1**.**

Examples of Some Aquatic Macrophytes Which Help in Heavy Metals Removal

Eichhornia crassipes (Water Hyacinth)

Eichhornia crassipes is by far the most prevalent of different seven water hyacinth types, develops quickly, incredibly tolerant of contamination, and therefore is utilised in sewage treatment owing to its large metal ions absorption capability (Ebel et al., 2007; Fang et al., 2007; Sanyal, 2017). Because of its high biomass output and favourable environmental circumstances, *Eichhornia crassipes* have higher arsenic (As) removal capability than some other submerged macrophytes (Mishra et al.,

Table 1. Bioaccumulation potentiality of various aquatic macrophytes.

Sl No.	Aquatic Macrophyte	Common Name	Metals/ Metal-loids	Reference
1	*Ceratophyllum demersum*	Rigid hornwort	Cd, Cr, As	Abdallah, 2012
2	*Eichhornia crassipes*	Water-hyacinth	Hg, Cu, Ni, Zn	Odjegba and Fasidi, 2007
3	*Lemna minor*	Common duckweed	Cr, Cu, Ni, Pb	Parra et al., 2011
4	*Mentha aquatica*	Water mint	Pb, Fe, Cr	Dinu et al., 2021
5	*Myriophyllum spicatum*	Spiked watermilfoil	Cu, Pb, Cd	Yabanli et al., 2014
6	*Nasturtium officinale*	Watercress	Ni, Cr, Zn	Kara, 2005
7	*Phragmites australis*	Common reed	Pb, Cr, Cu, Zn	Cicero-Fernández et al., 2016
8	*Pistia stratiotes*	Water cabbage	Mn, Cr, Pb, Fe	Odjegba and Fasidi, 2004
9	*Potamogeton crispus*	Curled Pondweed	Cu, Pb, Zn	Sood et al., 2012
10	*Potamogeton pectinatus*	Sago pondweed	Ni, Cu, Mn	Singh et al., 2014
11	*Salvinia herzogii*	Watermoss	As, Cd, Cr	Uka et al., 2012
12	*Salvinia minima*	Water spangles	Cr, Cd	Iha et al., 2015
13	*Scirpus sp.*	Bulrush	Al, Cd, Fe	Wang et al., 2009
14	*Spartina alterniflora*	Smooth cordgrass	Zn, As, Pb, Mn	Chen et al., 2018
15	*Spirodela intermedia*	Intermediate duckweed	Cr, Pb, Zn	Bala and Thukral, 2011
16	*Typha latifolia*	Broadleaf cattail	Ni, Zn, Mn	Hejna et al., 2020
17	*Vallisneria spiralis*	Eel grass	Ar	Rai et al., 2008

2008). That is the most problematic weed, occurring in great quantities year-round, and it is extremely effective for absorbing Pb, Zn, Mn, Cu, Ni by root system (Giraldo and Garzon, 2002; Singh et al., 2011). Water hyacinth could be the finest choice for removing heavy metals (David et al., 2003). *Eichhornia crassipes* are being used to remediate sewage to conserve water. It accomplishes this by lowering the amount of natural and synthetic nutrients (Singh et al., 2011).

Azolla caroliniana (Mosquito Fern)

The aquatic vascular Mosquito Fern (*Azolla Carolianía* Willd.) has been investigated as a potential biological filter for removing Cd from waste water. *Azolla* has a higher potential for harmful heavy metal accumulation and, therefore can remove contaminants from sewage (Rai and Tripathi, 2009).

Brassica juncea (Mustard Green)

Several experiments have shown that the *Brassica juncea* seems to be effective in bio-remediation of soil and absorbs Cd. Due to the obviously increased plant biomass, it also has a higher Zn extraction capability.

Zn, Cu and Pb's overall degradation efficiency was studied amongst several Brassicaceae: *Brassica juneca*, *Brassica carinata* and *Brassica oleracea*. *Brassica oleracea* demonstrated higher elimination of Zn and Cu through shoots. Zn and Pb absorption were found to be nearly consistent throughout all three plants (Szezyglowska et al., 2011).

Pistia stratiotes (Water Lettuce)

It is really a quickly growing freshwater macrophyte with such a high biomass. Because of its large rhizosphere, it has higher removal efficiencies for heavy metal ions. Deceased *Pistia stratiotes* have been discovered to be quite effective and worthy options for eliminating Pb and Cd from untreated wastewater (Singh et al., 2011; Miretzky et al., 2004). Throughout a one-month wastewater purification, it eliminated approximately 77% - 78% Cr and 91% - 92% Cu at various concentrations of such contaminants (Tabinda et al., 2020).

Lemnoideae (Duckweeds)

It is a freshwater macrophyte that floats on the surface of the water. It grows quickly in a variety of aquatic environments. The optimal temperature for plant growth varies between 5 to 35°C (Tabinda et al., 2020). Duckweed is most usually observed in pools and marshes. This plant has a good capability for hazardous metal removal from wastewater. *Lemna minor* develops well enough at pH levels ranging between 6 and 9, and it may absorb approximately 90% of Pb from wastewater. High concentrations of ammonia and nitrate may inhibit or decrease the growth rate of the duckweed (Caicedo, 2000).

Hydrilla verticillata (Hydrilla)

It is a freshwater weed that creates a thick coating throughout the entire stretch of water-body. The entire plant body can remove pollutants. Denny and Wilkins

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discovered that branches are much more effective than roots for absorbing toxic substances (Denny et al., 1987). While introduced to a strong Pb solution for about one week, it absorbed approximately 98% of the lead (Singh et al., 2011).

Spirodela intermedia (Intermediate Duckweed)

It is a drifting freshwater macrophyte that can absorb Cd, Pb and Cr from the effluent and wastewater and has a rapid development capacity under a variety of environmental circumstances (Cardwell et al., 2002). It can reduce the growth of algae by spreading themselves across the surface of the water body, limiting light availability, thus, eventually, photosynthetic rate (Hammouda et al., 1995).

Schoenoplectus californicus (California Bulrush)

It is commonly found all over the world. This is a macrophyte that grows beneath the water and absorbs nutritive substances and heavy metals and minerals from sediment via its roots. It can withstand very high heavy metal concentrations in water bodies (Arreghini et al., 2006).

Phyto-remediating aquatic macrophytes: management and treatment

With growing attention to the phyto-remediation of heavy metal polluted water by hyper accumulating plants, as well as the hopeful financial and ecological potentials of this technique, the outcome of plants with high heavy metal burdens would be a critical area of concern. However, a percentage of field research and experimentations have also shown that a few macrophytes are capable of accumulating heavy metals, which can be used for phytoremediation of heavy metal-contaminated water. Massive adoption of advanced technologies is still to be reviewed. Handling and disposal of the enormous quantity of phyto-remediating plants with high heavy metal concentrations will become a serious worry if this technique is increasingly implemented. If such phyto-remediating macrophytes are not safely disposed of, these may become just another cause of heavy metal pollution in ecosystem. Research findings on the treatment and disposal of heavy metal phyto-remediating aquatic macrophytes are currently insufficient. Just the build-up and disposal of metals from water by macrophytes would indeed be insufficient for such successful execution of such a new technology if indeed the phyto-remediating plants with greater heavy metal concentration were not properly managed and disposed of. There could be some procedures for disposing of high heavy metal overloaded macrophytes, although it is hard to ascertain whether or not it's ecologically and economically viable.

Incineration and carbonization

Macrophytes with high heavy metal content can also be used to make charcoal, and the by-product gas could be used as fuel. There really are two major issues with using aquatic phyto-remediating macrophytes to make charcoal. Firstly, the excess water must be reduced, and secondly, the ash matter of air-dried water is just too greater to make a quality fuel as such a final product. Carbonization is also made possible by the significant investments as well as the science and technology level required (Thomas and Eden, 2011).

Yet another alternative might be to incinerate the metal -accumulating macrophytes. In some places around the world, solar drying and straightforward incinerating of water hyacinths are used on a small scale to use all the ash as fertiliser. Because fresh macrophytes have a high water content, dehydration might take much longer. Furthermore, there really is no proof that arsenic is entirely removed after plants are burned. Combustion of arsenic-rich plants could also cause toxic elements emissions into the atmosphere. As a result, incinerating toxic elements hyper accumulating macrophytes would be harmful to the public and environmental health (Gunnarsson and Petersen, 2007).

Hydrolysis and fermentation

Hydrolysis and fermentation can generate fuel, including such ethanol, from phyto-remediating macrophytes, making macrophytes a good raw material. Hydrolysis and fermentation also necessitate the presence of simple yeast sugars, which may be in limited supply in phyto-remediating macrophytes. As a result, a kind of pre-treatment is required to create the sugar more readily accessible for hydrolytic cleavage. Pre-treatment necessitates a higher temperature, hydrofluoric acid, and pressurised reactors. Because of negative energy rebalancing, hydrolysis of aquatic plants to make fuel is now only viable whenever there is a huge market for ethanol as a liquid fuel. Even if it is cost-effective to create fuel from phyto-remediating aquatic plants, the arsenic level in bye-product sludge and the likelihood of recontamination should be investigated (Thomas and Eden, 2011; Gunnarsson and Petersen, 2007).

Briquetting

Briquettes are widely used in commercial food preparation. Briquetting would be an excellent treatment method for phyto-remediating aquatic plants. Briquetting could be used to treat water hyacinth. The briquettes are

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produced by solar heating the macrophytes for a few weeks, then falling to pieces, screening, and cutting the dehydrated water hyacinths into 6 mm large pieces. The chopped up water hyacinth could then be squeezed into lump charcoal or pellets (Thomas and Eden, 2011; Gunnarsson and Petersen, 2007).

Anaerobic digestion and biogas generation

Anaerobic treatment is a natural mechanism that degrades plant substances in the lack of air, producing biogas as a by-product. The gas could be used straightforwardly to prepare food, heaters, or generate electricity. Biogas produces valuable by-products and also has a beneficial impact on people's health. This, coupled with the increasing scarcity of fuel wood as well as the rise in the cost of carbon fuels, has increased the demand for biogas production. Because of all these benefits, the procedure may be well adapted to be used in underdeveloped nations. Macrophytes, including such water hyacinths, deteriorate quickly and produce a lot of gas (Thomas and Eden, 2011).

Production of biogas from phyto-remediation organic matter might be a feasible, fascinating, and ecologically sustainable concept for phyto-remediating aquatic species management. But even so, there are also some drawbacks to producing biogas from hyacinth. The greater lignin content could indeed decrease production, and the limited density can lead to large empty spaces with poor compression and reduced feed levels (Gunnarsson and Petersen, 2007). Despite the lack of extensive research on the topic, there is indeed a decent possibility that phyto-remediation plants could be used in anaerobic digestion. However, toxic elements concentration and speciation in biogas production effluent must be evaluated to protect its transfer into the surroundings.

Advances in phyto-remediation

Chemical Assisted Phyto-remediation

The phyto-remediation potency is determined by the phyto-availability of various metals found in the soil (Lombi et al., 2001). Different chemicals have proven to be an effective method for increasing heavy metal bioavailability in plants. Biofertilizers and chelating materials are frequently used to lower soil acidity, improving plant bioavailability and bio-absorption. In tobacco, decreasing the pH with a chelating substrate resulted in higher Cadmium Bioaccumulation. In several research, the use of EDTA increased phyto-extraction and bio-absorption of Cadmium, Zinc and copper (Farid et al., 2013; Hadi et al., 2014).

Some chelating compounds, such as ethylene glycol tetra-acetic acid (EGTA) and diethylene triamine penta-acetic acid (DTPA), have already been shown to be effective chelating agents in increasing heavy metal bioavailability and phyto-remediation (Pereira et al., 2010). Plants' phyto-extraction potency can also be increased by preparing them to withstand a lot of stress and toxic effects. Salicylic acid has indeed been reported to be beneficial in alleviating metal stress tolerance in plants, resulting in increased phyto-extraction ability (Emamverdian et al., 2020; Shaheen et al., 2015

The use of various chemicals seems to have some disadvantages as well. The applicable contaminant might indeed occasionally cause toxic effects, leach into underground water, and disrupt heavy metal absorption in plants (Nowack et al., 2006). The chemical compounds used may frequently form a complex with toxic substances that have non-biodegradable properties, resulting in a source of additional pollution. Chelators have the potential to disrupt plant development. Due to the toxic impacts of chelators, this could result in reduced development of root systems, shoots, and biomass (Nedelkoska and Doran, 2000). The adverse consequences of chelators can be reduced by using sufficient quantities of chelators, applying them carefully, and recognising the moisture leakage methodology (Navari-Izzo and Quartacci, 2001).

Phyto-remediation Assisted by Microorganisms

Plant-associated microorganisms play an important role in heavy metals removal from soil and water. These microbes influence heavy metal accessibility and deposi tion in the soil environment (Ma et al., 2015). Bio-augmentation of microphytes with specific and modified bacteria has previously received a lot of attention in phytoextraction (Fang et al., 2016). Rhizobacteria were reported to boost plants growth, immune function and decrease metal-induced toxic effects in bio-augmented plants (Afzal et al., 2014).

Mycorrhizal fungi and endophytic microbes in soil layers enhance vegetation growth and increase vegetation phytoremediation potency by increasing metal availability, absorption, deposition, and lowering metal stress. Additionally, endophytic bacteria improve plant phytoremediation ability by increasing soil quality through the manufacturing of growth factors as well as the availability of adequate nutrients (Doty, 2008; Phetcharat and Duangpaeng, 2012; Zhang et al., 2013). Endophytic fungi inside the root system establish a relationship with the root system and play a significant role in phyto-remediation (Conix et al., 2017). This plant-fungi relationship improves access to necessary nutrient elements via their mycelium network, modifies extracts, changes soil pH, and increases the bioavailability of various metals to corresponding plants (Chen et al., 2003; Mathusaravanan et al., 2018).

Plants that have been genetically modified

The use of transgenic plants in phytoremediation seems to be an innovative way of increasing the efficacy of phyto-remediation (Doty, 2008; Kozminska et al., 2018). Transgenic plants contain individual genes that boost the metabolic activity, intensification, and absorption of chemical contaminants. The perfect plant for phyto-remediation must have the following features: high biological production, adaptation to local and target environments, and a well-established transition procedure. Transgenic plants also improve contaminant detoxification and the accumulation of toxicants in the food web (Kozminska et al., 2018; Van Aken, 2008). Transgenic plants are seen to be effective at treating polyphenols, carbon tetrachloride, and exploding pollutants (Eapen et al., 2007; Macek et al., 2008).

Plants can be genetically modified to break down organic contaminants inside the root system. Transgenic plants don't really easily absorb and pile up contaminants in this case; instead, integrating genes produce enzymes that break down organic contaminants inside the rhizobial area (Kawahigashi, 2009). Because all metal biotransformation and relocation take place in the rhizosphere by the root system, this technique furthermore solves the issue of plant cultivation and the ability to handle stuffed with toxic elements (Darrah et al., 2006). The diversification of the microbial population, enhanced metabolism rate, the discharge of exudates and proteases, and constant interaction among root systems and pollutants are all credited to genetically modified plants' capacity (Kidd et al., 2007; Kumar et al., 2018).

Biomass from Non-Living Plants

Nonliving plant biomass is used fruitfully for metal accumulation and restoration. The use of dehydrated and decaying vegetation to eliminate metals from moisture has attracted increasing attention in recent years since it is simple to handle as well as being a cost-effective general method (Han et al., 2018; Kaewsarn, 2002). The dehydrated roots of water hyacinth demonstrated the ability to successfully eliminate pollutants from effluent (Sanmuga Priya et al., 2017; Wang et al., 1998). Various studies have found that organic material from underwater plant species including such *Eichhornia crassipes* and *Salvinia herzegoi* are used effectively like an extraordinary sorbents material for such abolishment of Nickel, Cadmium, Copper etc (Wang et al., 1996; Wang et al., 2019).

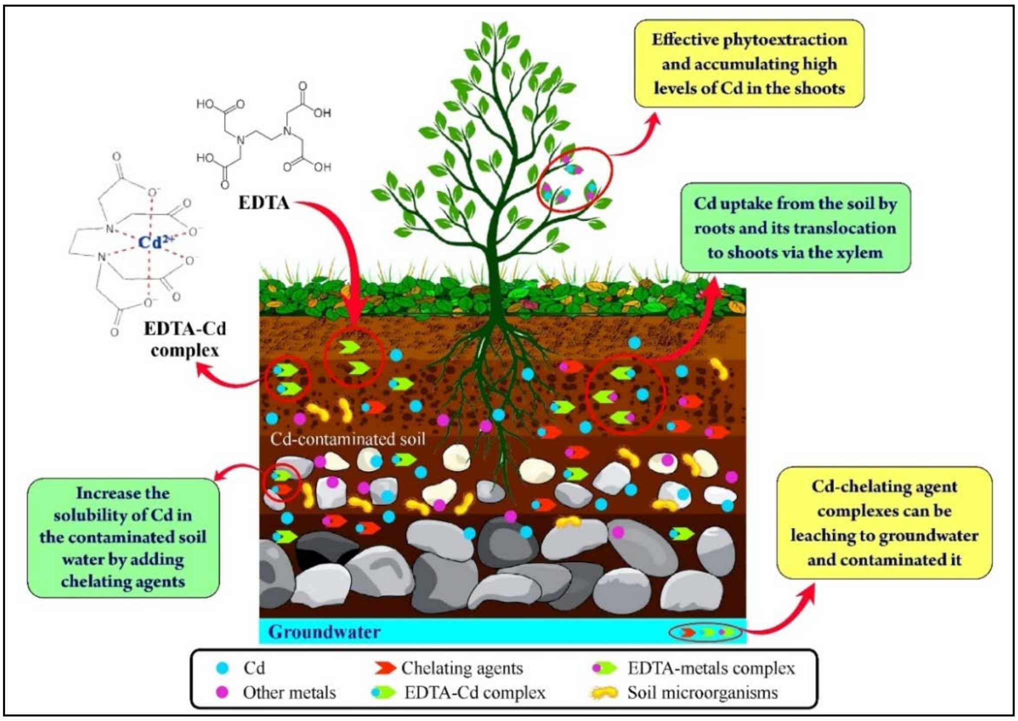

Figure 5. Phytoremediation by adding chelating agents (EDTA) to eliminate Cd from contaminated soil

Significance of aquatic plants in wastewater phyto-remediation

Because of its exquisiteness and cost-effectiveness, phyto-remediation of toxic substances with macrophytes has received a lot of attention (Bokhari et al., 2015). Heavy metal ions are removed by macrophytes through

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uptake or surface adsorption, integrated into their structures, and afterwards accumulated in specific bounded forms (Rai et al., 1995). Pollutants from sewage are remedied by macrophytes, causing fewer damage to the ecosystem (Sas-Nowosielska et al., 2007). This review summarises the efficacy of these macrophytes in the remediation of various types of wastewater.

Municipal Wastewater Phytoremediation

Municipal sewage water poses a major threat to aquatic ecosystems because it is a major source of heavy metal contamination. Zinc, Copper, Nickel, Lead, Mercury are possibly main sources of pollution that can cause serious physical health impacts, as well as bio-magnification and potential toxicity. The application of macrophytes to remove heavy metals and toxicants from effluent and sewage and wastewater is now a widespread and experimental procedure. Plants can also be used as bio-accumulators because their biomass contains high amounts of heavy metals (Akpor and Muchie, 2010).

Industrial Wastewater Phyto-remediation

Industrial effluents outflow into water and soil continues to pose a much more significant threat to public health, living creatures, as well as other assets. In conjunction with recently developed technology and biological techniques, Phyto-remediation has aided in the effective elimination of toxic metals from industrial effluents via phyto-extraction and rhizo-filtration. In the Swabi region of Pakistan, twelve macrophytes have been tested for their phyto-remediation functionality for various heavy metals originating from industrial effluents. The results showed that all these macrophytes eliminated toxic metals from industrial effluents with extraordinary removal capability (Cheraghi et al., 2009)

Phyto-remediation of Textile Wastewater

Among many other manufacturing industries, effluent from textile factories is regarded to be the most contaminated. Both biological and chemical pollutants are produced in textile industry wastewaters during the dyeing and finishing processes. Metals in textile wastewater are more poisonous, posing a greater health hazard. Water hyacinth is widely recognised as the best candidate for phyto-extraction of textile industry wastewaters among macrophytes. Aquatic plants like *Salvinia molesta* and *Pistia stratiotes* can remove Zn, Cd, Cu from textile wastewater at a density of 25% (Soares et al., 2017).

Phyto-remediation of Mining Effluents

Mining operations have a negative impact on the entire surroundings and put an enormous strain on local plant and animal life. Mining activities involve the outflow of massive amounts of hazardous pollutants into the aquatic system. Mining effluents contain much relatively high concentrations of various contaminants such as calcium carbonate and heavy metals. Contaminants derived from mining effluents are indeed very highly persistent and therefore can easily pile up inside the land, water, and silt. They also have the capacity to penetrate the food web via bio-magnification and absorption, thereby influencing animal and human health. To eliminate heavy metals, various techniques have been developed all around the world. Phyto-remediation is a technique that has shown impressive outcomes in the effective elimination of heavy metals originating from mining effluents through the use of macrophytes (Mishra et al., 2009).

Landfill Leachate Phyto-remediation

Land filling and open dumping are by far the most popular methods of disposing of solid wastes all around world. Leachate is formed due to the interplay of waste disposal, soil moisture, and various types of fluid pollutants discarded in the dumpsite. Infrequent as well as non-uniform infiltration of water content occurs in landfills via household waste, is resulting in the production of leachates. If leachate is not appropriately controlled, it can quickly lead to a wide range of negative environmental and health consequences. One of the main constraints in leachate treatment is the lack of adequate treatment methods for the massive amounts of leachates produced globally (Nagendran et al., 2006).

To remove contaminants from effluents, different physiochemical approaches are being used. Sad to say, those very same methods are usually both complex and costly. In leachate treatment & management, finding a cost-effective and environmentally friendly solution is a primary concern. Macrophytes can survive in the heavily polluted landfill leachate burden without substantially reducing biomass and productivity growth. In such a floating mechanism, *Eichhornia crassipes* has demonstrated a strong potential for stripping away various heavy metals from leachates, thereby lowering the contamination intensity of the leachates (El-Gendy et al., 2006).

Significance of aquatic plants in constructed wetlands

During the last few years, sewerage treatment via constructed wetland has indeed been excellently implemented around the globe as an acceptable sewerage treatment option. Constructed wetlands are intended to treat specific wastewaters in a confined space. In constructed wetlands, a wide variety of effluents, including farmland, municipal, leachates, stormwater runoff, and

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industrial effluent, can be treated. The constructed wetland provides a relatively simple and low-cost alternative for attempting to control contamination of water without disrupting normal wetlands' resources. Macrophytes are an essential component of constructed wetland for treating wastewater (Madera-Parra et al., 2015). The root system provides huge support to microbial populations that deal with the required reforms in metal ions, various substances, and nutrients. As a result, macrophytes in constructed wetlands aid in the bioremediation of contaminated sewage water and serves as a sink for pollutants (Abdallah, 2012).

Benefits of phyto-remediation

Phyto-remediation, being a biological process, has several advantages.

(a) The method does not affect the surrounding ecology and preserves nature.

(b) Most effective for deep and low-level polluted areas.

(c) It is possible to remediate a wide range of environmental pollutants.

(d) The concept is visually appealing and popular with the general audience. It is appropriate for situations where all the other strategies are ineffective. It is less expensive than that other remedial methods.

(e) In comparison to certain other approaches, phytoremediation offers lower management and implementation expenses.

(f) Planting on polluted soils can help avoid metals leaching and runoff. Plants that grow quickly and produce a lot of biomass can sometimes be utilised to generate energy.

(g) Phyto-remediation may aid in the recycling and recovering of precious metals.

(h) This process is the least detrimental to the environment and humans who live in that area.

Drawbacks and challenges of Phyto-remediation

Although phyto-remediation is an environmentally favourable procedure, it has some certain drawbacks.

(a) It is a relatively lengthy clean-up procedure.

(b) This can contaminate the entire food web via transporting toxins from the waterways or soil to grazing animals.

(c) This technique has a shallower restoration area that ranges between 12 inches to 15 feet.

(d) High heavy metal pollution may be hazardous to plants; however certain plants are quite effective at removing toxins.

(e) Vegetation becomes poisonous to animals and the common people when toxic elements and pollutants accumulate, thus, access to certain areas should be limited.

(f) Plant can acquire average levels of pollutants from soil and groundwater, making them unsuitable for severely polluted environments.

The growth of phyto-remediation as such an environmentally beneficial method will face several hurdles in the near future, such as the involvement of indigenous capability as well as the establishment of efficient federal regulations. There is indeed a scarcity of expertise in phytoremediation, as well as an absence of appropriate data, quality criteria, and expense analyses.

Conclusion & future prospects

As a chronic pollution, contaminants in the natural ecosystem must be totally eliminated for a truly restorative goal. Phyto-remediation appears to be a somewhat intrusive, cost-effective, and ecologically friendly clean-up solution. A most important aspect of phyto-remediation is indeed the selection of suitable plants. Like other hyper accumulator plants, Macrophytes play a highly active role in the cleanup of heavy metals from contaminated sites. Aquatic plants are used efficiently for heavy metal elimination in both bioaccumulation and bio-absorption.

Aquatic macrophytes' retention and bio-accumulation of heavy metals are regulated by complex interactions, transportation, and chelating agent actions. Genetic modification improves plant uptake and tolerating capability, demonstrating its outstanding use in boosting phyto-remediation efficacy. At the cellular scale in vegetation, many substantial measures have been assessed that favour recombinant approaches to intercede with plant's transition metal proportion. Genetically modified plants have a greater degree of tolerance and metals absorption capability. Consequently, gene modification has indeed been effectively examined in land plants; however, genetic modification of aquatic species to improve the heavy-metal adsorption performance is still in its early stages.

Subsequently, plant biomass may be utilised to produce methane and livestock feeds. Aquatic species bioremediation, like some other traditional physiochemical treatments, doesn't really involve post-filtration and may efficiently remove a vast amount of contaminated soil and water. According to the current research, the advantages of employing aquatic vegetation to remove pollutants are enormous since this technique treats not only harmful pollutants but also is cost-effective & aesthetically appealing, and also beneficial to the long-term viability of entire ecosystem.

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