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A Systematic Review on Phytoremediation Technology: Removal of Pollutants from Waste Water and Soil

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***Abstract*: Phytoremediation is solar energy driven clean up, eco-friendly and cost effective technology. Use of this technology to reduce pollutant from waste water, soil and heavy metal uptake. Some recommended plants which are commonly used in phytoremediation have capacity to reduce the contaminant of the water. According to previous studies, several plants have a high potential to remove or reduce the pollutants and also work as a bioaccumulator which can be used for phytoremediation process of heavy metals. The main aim of this review is to give the systematic information about phytoremediation.**

***Keywords*: Environmental pollution, Phytoremediation, Heavy metals, Soil, waste-water**

1. Introduction

Phytoremediation can be used to clean up organic contaminants from surface water, ground water, leachate, municipal and industrial wastewater (Negri et al., 1996). Phytoremediation is a cost effective and feasible sustainable method for removal of contaminants. This technology also known as “green” technology, has established rising attention after the discovery of hyper accumulating plants which are able to accumulate, translocate, and concentrate high amount of certain toxic elements in their above ground parts (Paz-Alberto and Sigua 2013) Phytoremediation includes several processes viz., phyto-extraction, phyto-degradation, rhizo-filtration, phyto-stabilization and phyto-volatilization (Chatterjee et al., 2013).In other side heavy metals become a major concern than other environmental pollutions because heavy metals can’t be destroyed by degradation. In several studies shows, significant efforts have been made to eradicate heavy metals from contaminated environments, including physical, chemical or biological processes (Ayangbenro & Babalola 2017). Each remedial alternative has advantages and disadvantages in terms of cost efficiency and environmental safety. For example, heavy metal removal from wastewater has been traditionally carried out by chemical precipitation because it is relatively simple and inexpensive to operate (Wuana and Okieimen, 2011). Meanwhile, chemical precipitation is advisable only for cleaning up highly contaminated wastewater and it is ineffective when the metal ion concentration is low.(Fu and Wang 2011). 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 and carcinogenic, are feasible targets of phytoremediation (Peuke and Rennenberg, 2005). Thermal treatments can be completed in short time periods (in comparison with biological treatment), but are typically the most costly of all of the available methods (Pavel and Gavrilescu, 2008). In terms of biological treatment, although many microorganisms were found to be capable of degrading toxic compounds, microbial bioremediation approaches suffer from certain inherent limitations (Ojuederie and Babalola 2017). The development of novel technologies based on plants and associated microbes may provide a more promising strategy to reduce environmental and human health risks associated with heavy metal contamination because it gives toxic effects on human health and cause severe diseases (Tchounwou et. al., 2012).

2. Action of Mechanisms

There are several different types of phytoremediation mechanisms which includes,

A. Rhizosphere biodegradation

Rhizodegradation is the breakdown of contaminants in the soil through microbial activity that is enhanced by the presence of the rhizosphere and is a much slower process than phytodegradation (Shukla et al., 2013). Microorganisms consume and digest organic substances for nutrition and energy. Some microorganisms can digest organic substances such as fuels or solvents that are harmful to human health and break them down into harmless products through biodegradation (Tangahu et al., 2011). Natural substances released by plant roots supply nutrients to microorganisms, which increases their ability to biodegrade organic pollutants. Biodegradation is also facilitate in loosen the soil and transport water to the area (Bot, A., and Benites, J. (2005)

B. Phyto-stabilization

Phyto-stabilization refers to the use of plant species to immobilize contaminants in the soil and ground water through absorption and accumulation by roots, or precipitation within the root zone of plants (rhizosphere) (Gupta, P 2019). It reduces the mobility of the contaminant and prevents relocation to the ground water or air, and it decrease bioavailability for entry into the food chain. Also prevent in leaching and soil dispersion (Wuana and Okieimen,2011). This mechanism can be used to restore a vegetative cover at sites where natural vegetation is deficient due to high metal concentrations in surface soils or physical disturbances to surficial materials (Prasad, M. N. V. (2004). This technology may enhance the degradation of organic contaminants such as pesticides and hydrocarbons via microbial activity associated with the plant roots that accelerates the transformation of these contaminants into nontoxic form (Bolan, N. S 2011). Phytostabilization can be enhanced by using soil amendments that are effective in the immobilization of metal(loid)s and plant species that are tolerant of high levels of contaminants (Kumpiene et al., 2008).

C. Phyto-accumulation (also called phyto-extraction)

This process refers to the uptake and translocation of metal contaminants in the soil by plant roots into the above ground portions of the plants. Phytoextraction is mainly used for the treatment of polluted soils and wastes containing metals (USEPA, 2000). Studies shows that water-soluble metals are taken up by plant species selected for their ability to take up large quantities of lead (Pb) (Tangahu, B. V 2011). The metals are stored in the plants aerial shoots, which are harvested or are disposed of as a hazardous waste. As a general rule, readily bioavailable metals for plant uptake include cadmium, nickel, zinc, arsenic, selenium, and copper. Moderately bioavailable metals are cobalt, manganese, and iron. Lead, chromium, and uranium are not very bioavailable (Wuana and Okieimen,2011).

Discovery of metal hyperaccumulator species shows that plants have the potential to remove metals from contaminated soils (Raskin and Ensley, 2000). A hyperaccumulator is a plant species capable of accumulating 100 times more metal compare to a common non-accumulating plant (rew, A. (2007). Metals such as nickel, zinc and copper removed by this technique, these are the best candidates because it has been shown that they are preferred by a majority of plants (approximately 400) that uptake and absorb unusually large amounts of metals (Etim, E. E. (2012). The cost of phytoextraction is very low when compared to conventional methods. In addition, the amount of waste material that must be disposed of is substantially decreased (up to 95%) (USEPA, 2000) and in some cases, the contaminant can be recycled from the contaminated plant biomass (Henry, J. R. (2000). The use of hyperaccumulator species is partially slow growth, shallow root system, and small biomass production. This approach is emerging as a novel tool with greater potential for achieving sustainable development. It also beneficial for decontaminate metal polluted soil and water (Wenzel et al. 2003).

The method is additionally usually limited to metals and other inorganic compounds in soil or sediment (Etim, E. E. (2012). In sort for this clean-up method to be possible, the plants must (1) extract large concentrations of heavy metals into their roots, (2) translocate the heavy metal into the surface biomass, and (3) produce an huge quantity of plant biomass. In addition, remediative plants must have mechanisms to tolerate high metal concentrations accumulated in their shoots (Brennan and Shelley, 1999).

D. Rhizofiltration (Hydroponic systems for treating water streams)

Rhizofiltration is similar to phyto-extraction, but the plants used for cleanup is raised in greenhouses with their roots in water. This system can be used for ex-situ groundwater treatment. That is, groundwater is pumped to the surface to irrigate these plants USEPA, 2000). Typically hydroponic systems utilize artificial soil medium, like sand mixed with perlite or vermiculite. As the roots become saturated with pollutants, they are harvested and disposed. This technique is usually exploited in groundwater (either in place or extracted), surface water, or wastewater for removal of metals or other inorganic compounds (EPA, 2000). Rhizofiltration are often used for Pb, Cd, Cu, Ni, Zn, and Cr, which are primarily retained within the roots (USEPA, 2000). In one study, after just one hour of treatment, sunflowers reduced lead concentrations significantly (Raskin and Ensley,2000). Rhizofiltration is that the adsorption or precipitation onto plant roots or absorption into the basis of contaminants that are in solution surrounding the root zone. The plants to be used for cleanup are raised in greenhouses with their roots in water instead of soil (Tangahu, B. V 2011). To acclimate the plants once a huge rootage has been developed, contaminated water is collected from a waste site and delivered to the plants where it is substituted for their water source. The plants are then planted within the contaminated area where the roots take up the water and therefore the contaminants alongside it.

E. Phyto-volatilization

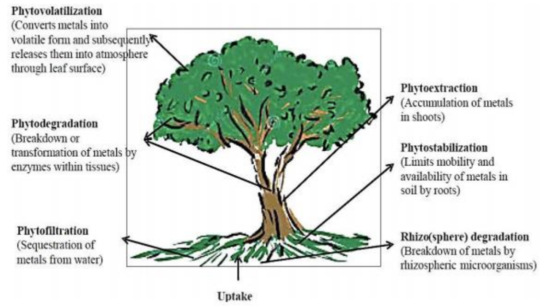
This involves the utilization of plants to require up contaminants from the soil, transforming them into volatile forms and transpiring them into the atmosphere (USEPA, 2000). Phytovolatilization can occur with pollutant present in soil, sediment, or water. Mercury is that the primary metal contaminant that this process has been used (rew, A. (2007). It has been found to occur with unstable organic compounds, including trichloroethene, inorganic chemicals that have volatile forms, like selenium, and arsenic (EPA, 2000). The benifit of this method is that the contaminant, mercuric ion, could also be transformed into a less toxic substance. Phytovolatilization refers that the uptake and transpiration of a contaminant by a plant, with free of the contaminant or a modified sort of the contaminant to the atmosphere from the plant. Phytovolatilization occurs as growing trees and other plants take up water and therefore the organic contaminants. Some of these contaminants can undergo the plants to the leaves and volatilize into the atmosphere at comparatively low concentrations (Dushenkov, V 1995).

F. Phyto-degradation

In this process, plants actually metabolize and destroy pollutants within plant tissues. It involves the degradation of complex organic molecules to simple molecules or the inclusion of these molecules into plant tissues (Trap et al., 2005). Phytodegradation has been observed to remediate some organic contaminants, such as chlorinated solvents, herbicides and it can address contaminants in soil, sediment, or groundwater (EPA, 2000). Phytodegradation, also called phytotransformation, is the breakdown of contaminants taken up by plants through metabolic processes within the plant, or the breakdown of contaminants external to the plant through the effect of compounds (such as enzymes) produced by the plants. Pollutants are degraded, incorporated into the plant tissues, and used as nutrients.

G. Hydraulic Control

In this process, trees indirectly remediate by controlling groundwater movement Hydraulic control can therefore be used to address a wide range of contaminants in soil, sediment, or groundwater (EPA, 2000). It should be noted that hydraulic control is also an easy phytoremediation mechanism for control of groundwater contamination in particular, because the characteristics of the contaminants are not as significant to the success of the technique. Trees act as natural pumps when their roots reach down towards the water table and make a dense root mass that takes up large amount of water. For example, a popular tree pulls out of the ground 30 gallons of water per day, and a cottonwood can absorb up to 350 gallons per day (Sharma et al., 2018).



3. Sources of heavy metals and soil water pollution

Removal of pollutants and heavy metals is major concern in phytoremediation as well as its a worldwide issue. All countries have been affected, harshness of pollution vary enormously. In Western Europe, 1 400 000 sites were full of heavy metals (McGrath et al., 2001), of which, over 300 000 were contaminated, and therefore the estimated total number in Europe might be much larger, as pollution problems increasingly occurred in Central and Eastern European countries (Gade, 2000). In USA, there are 600 000 brown fields which are contaminated with heavy metals require reclamation (Lone MI et al 2008). According to government statistics, mine has contaminated over 19 000 km folks streams and rivers from heavy metals, acid mine drainage and polluted sediments. More than 100 000 ha of cropland, 55 000 ha of pasture and 50 000 ha of forest are lost (Ragnarsdottir and Hawkins, 2005). Studies shows that the problem of land pollution is a great challenge in China, where one-sixth part of total arable land has been polluted by heavy metals, and more than 40% has been degraded to varying degree because of erosion and desertification (Liu, 2006). Soil and water pollutions are additionally main problems in India, Pakistan and Bangladesh, where small industrial units are pouring their untreated effluents within the surface drains, which cover near agricultural fields. In these countries raw sewage is usually used for producing vegetables near big cities.

Table 1
Different sources of heavy metals

Heavy Metals	Sources	Reference
As	Semiconductors, petroleum refining, wood preservatives, animal feed additives, coal power plants, herbicides, volcanoes, mining and smelting	Nriagu, and Azcue, (1994). Walsh *et al*., 1979)
Cu	Electroplating industry, smelting and refining, mining, biosolids	Xiaomei, L., Qitang, W., & Banks, M. K. (2005
Cd	Geogenic sources ,anthropogenic activities,metal smelting and refining, fossil fuel burning, application of phosphate fertilizers, sewage sludge	Alloway, B. J. (Ed.). (2012). Kabata-Pendias, 2001)
Cr	Electroplating industry, sludge, solid waste, tanneries	(Knox *et al*., 1999)
Hg	Volcano eruptions, forest fire, emissions from industries producing caustic soda, coal, peat and wood burning	Lindqvist, 1991)
Pb	Mining and smelting of metalliferous ores, burning of leaded gasoline, municipal sewage, industrial wastes enriched in Pb, paints	(Gisbert *et al*., 2003; Seaward and Richardson,1990)
Ni	Volcanic eruptions, land fill, forest fire, bubble bursting and gas exchange in ocean, weathering of soils and geological materials	(Knox *et al*., 1999)
Zn	Electroplating industry, smelting and refining, mining, biosolids	(Liu *et al*., 2005)
Pb	Mining and smelting of metalliferous ores, burning of leaded gasoline, municipal sewage, industrial wastes enriched in Pb, paints	(Gisbert *et al*., 2003; Seaward and Richardson,1990)

4. Role of plants in phytoremediation

Many plants are used in phytoremediation, they remediate the pollutants through different mechanism. About 500 plant species are identified to accumulate toxic inorganic elements, representing about 100 land plant families (Kramer 2010). Many plant families are utilized for metal phytoremediation purposes Family Brassicaceae is a significant taxon of metal hyperaccumulators (Baker and Brooks 1989). Family Salicaceae, including *Populus* and *Salix* genera, to be a highly investigated plant family (Tangahu et al. 2011).

Salix: As a fast-growing tree species has some advantages over herbaceous species, like a deeper rootage, high productivity and transpiration activity; it represents a promising resource in mitigating impacts of environmental degradation. Remediation by willow plantations can clean or ease hazardous waste, stabilize, restore a site and produce wood for fuel and bat industry (Wani et al., 2011). Willows planted as vegetation filters will help in excess nutrient uptake, reduce erosion, provide habitat for varied organisms above and below the water level, and enhance a site's visual characteristics. Salix are cosmopolitan across North America and therefore the geographic range of abandoned hardrock mines (Mosseler, A., & Major, J. (2017). It is best practice to use native vegetation since it requires less management and is already acclimated to the area's climate and seasons. Willows' ability to dry swampy soils is documented by farmers. Historical references have even mentioned that credit to high rates of evapotranspiration (phreatophyte-type of vegetation), willows planted in areas full of malaria were the foremost effective for dehydration the world (Going, 1903) [50]. The establishment of willow vegetative buffer zones or biocurtains, for capping landfills, sewage treatment plants, steelworks and waste dumps has been applied in phytostabilization projects that aim to regulate soil water (Craven, 1994). Willows' ability to requisition of heavy metals and other contaminants in their root systems, uncertain their circulation within the environment, are often of great practical use (Ettala, 1988).

Populus: Species belonging to the Populus genus (poplars) are suitable candidates for phytoremediation. These trees have a high biomass production, extensive roots, high rates of transpiration and simple propagation (Guerra, F et al., 2011). Also, the wide genetic diversity comprised with this genus and therefore the development of multiple biotechnologies and knowledge resources allow a genetic improvement supported traditional and biotechnological approaches. Studies applied in several experimental conditions show that poplars exposed to Cu, Cd and Zn exhibit distinct tolerance levels and metal accumulation patterns. Poplars act as some sort of "water pumps" and transpire enormous amounts of water up to 200 liters for 5 year old tree (Newmann et al., 1997). This response depends on specific genotypes. The plants most used and studied are poplar trees. The U.S. Air Force has used poplar trees to contain trichloroethylene (TCE) in groundwater. In Iowa, EPA demonstrated that poplar trees acted as natural pumps to stay toxic herbicides, pesticides, and fertilizers out of the streams and groundwater (Kamath, Ret al., 2004).

Eucalyptus: Eucalyptus species have been proposed for phytostabilization of contaminated soils because of their moderate to low rates of heavy metal accumulation into aboveground biomass, thus reducing the risk of transmission of contaminants into the food web (Arriagada, C. A et al.,2007, King, D. Jet al., 2008). However, some eucalyptus trees could accumulate, under experimental conditions, a certain amount of heavy metals into their shoots (Arriagada, C. A et al.,2007, Fine, P et al., 2013, Mok,et al., 2013). Different Eucalyptus species such as globules, camaldulenses are help in phytoremediation. Eucalytpus globulus shows good ecological conditions in humid temperate climates, there are few studies that have showed their great potential in contaminated areas and important biomonitors of environmental quality. Some studies shows their rapid growth, well-developed root systems and widespread distributions in Brazil give species such as Eucalyptus *maculata and E. urophilla* (i.e heavy metal tolerant) significant potential for use in restoration programs of contaminated soils (Gomes et al, 2012).

5. Advantages of Phytoremediation

The major advantages of Phytoremediation to reduce the concentration of heavy metal ions and the use of low cost biosorbent materials (Rakhshaee and Pourahmad, 2009). Phytoremediation is a new approach for the removing contamination from soil, water, and ambient air (Van Ginneken et al., 2007). Phytoremediation also contribute to the improvement of polluted soils and waste water, those with high pollutant levels. It is applicable to a variety of toxic metals and radionuclides, minimal environmental disturbance, elimination of secondary air or water borne wastes and public acceptance (Liu et al.,2000). Phytoremediation is a complete in situ, easy to transportation and off-site processing costs. Compared to other systems, it's generally aesthetically pleasing and well accepted (Ghosh and Singh, 2005).

6. Conclusion

There are several ways in which plants are used to clean or remediate contaminated sites (waste water and soil). To remove pollutants from soil, water and air, plants can break down, or degrade organic pollutants and stabilize inorganic contaminants by acting as filters/traps. The success of phytoremediation at a given site cannot always be attributed to only one in every of these mechanisms because a mixture of mechanisms could also be at work. Phytoremediation is a low cost, solar power driven and natural cleanup technique, which are most useful at sites with shallow, low levels of contamination. Phytoremediation is useful for treating a large form of environmental contaminants and are effective with or in some cases, in situ of mechanical cleanup methods. Phytoremediation harnesses natural processes to help within the clean the pollutants of the environment. The mechanisms by which plants promote the removal of pollutants are varied, including uptake and concentration, transformation of pollutants, stabilization, and rhizosphere degradation, during which plants promote the expansion of bacteria underground within the root zone that successively break down pollutants. Phytoremediation is agreeable to a spread of organic and inorganic compounds and should be applied either in place or ex situ. In situ applications decrease soil disturbance and therefore the possibility of contaminant from spreading via air and water, reduce the quantity of waste to be land filled (up to 95%) and are low-cost compared with other treatment methods. In addition to the current, it's easy to implement and maintain, doesn't require the utilization of costly equipment or highly specialized personnel and is environmentally friendly and aesthetically pleasing to the public.

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References

[1] Alloway, B. J. (Ed.). (2012). Heavy metals in soils: trace metals and metalloids in soils and their bioavailability (Vol. 22). Springer Science & Business Media.
[2] Arriagada, C. A., Herrera, M. A., & Ocampo, J. A. (2007). Beneficial effect of saprobe and arbuscular mycorrhizal fungi on growth of Eucalyptus globulus co-cultured with Glycine max in soil contaminated with heavy metals. *Journal of environmental management*, *84*(1), 93-99.
[3] Ayangbenro, A., & Babalola, O. (2017). A new strategy for heavy metal polluted environments: a review of microbial biosorbents. *International journal of environmental research and public health*, *14*(1), 94.
[4] Baker, A. J. M., & Brooks, R. (1989). Terrestrial higher plants which hyperaccumulate metallic elements. A review of their distribution, ecology and phytochemistry. *Biorecovery.*, *1*(2), 81-126.
[5] Bolan, N. S., Park, J. H., Robinson, B., Naidu, R., & Huh, K. Y. (2011). Phytostabilization: a green approach to contaminant containment. In *Advances in agronomy* (Vol. 112, pp. 145-204). Academic Press.
[6] Bot, A., & Benites, J. (2005). The importance of soil organic matter: Key to drought-resistant soil and sustained food production (No. 80). Food & Agriculture Org.
[7] Brennan, M. A., & Shelley, M. L. (1999). A model of the uptake, translocation, and accumulation of lead (Pb) by maize for the purpose of phytoextraction. *Ecological Engineering*, *12*(3-4), 271-297.
[8] Chatterjee, S., Mitra, A., Datta, S., & Veer, V. (2013). Phytoremediation protocols: an overview. In *Plant-Based Remediation Processes* (pp. 1-18). Springer, Berlin, Heidelberg.
[9] Craven, D. R. J. (1994). Hallside steelworks project. *Willow Vegetation Filters for Municipal Wastewater and Sludges, Swedish University of Agricultural Sciences, Uppsala*, 169-172.
[10] Dushenkov, V., Kumar, P. N., Motto, H., & Raskin, I. (1995). Rhizofiltration: the use of plants to remove heavy metals from aqueous streams. *Environmental science & technology*, *29*(5), 1239-1245.
[11] Etim, E. E. (2012). Phytoremediation and its mechanisms: a review. *Int J Environ Bioenergy*, *2*(3), 120-136.
[12] Etim, E. E. (2012). Phytoremediation and its mechanisms: a review. *Int J Environ Bioenergy*, *2*(3), 120-136.
[13] Ettala, M. (1988). Evapotranspiration from a Salix aquatica plantation at a sanitary landfill. *Aqua fennica*, *18*(1), 3-14.
[14] Fine, P., Rathod, P. H., Beriozkin, A., & Mingelgrin, U. (2013). Uptake of cadmium by hydroponically grown, mature Eucalyptus camaldulensis saplings and the effect of organic ligands. *International journal of phytoremediation*, *15*(6), 585-601.
[15] Fu, F., & Wang, Q. (2011). Removal of heavy metal ions from wastewaters: a review. *Journal of environmental management*, *92*(3), 407-418.
[16] Gade, L. H. (2000). Highly polar metal–metal bonds in "early–late" Hetero dimetallic complexes. *Angewandte Chemie International Edition*, *39*(15), 2658-2678.
[17] Ghosh, M., & Singh, S. P. (2005). A review on phytoremediation of heavy metals and utilization of it's by products. *Asian J Energy Environ*, *6*(4), 18.
[18] Gisbert, C., Ros, R., De Haro, A., Walker, D. J., Bernal, M. P., Serrano, R., & Navarro-Aviñó, J. (2003). A plant genetically modified that accumulates Pb is especially promising for phytoremediation. *Bio-chemical and biophysical research communications*, 303(2), 440-445.
[19] Going, M. (1908). *With the trees*. Baker & Taylor.
[20] Gomes, M. P., Marques, T. C. L. L. S. M., Carneiro, M. M. L. C., & Soares, Â. M. (2012). Anatomical characteristics and nutrient uptake and distribution associated with the Cd-phytoremediation capacity of Eucalyptus camaldulenses Dehnh. *Journal of soil science and plant nutrition*, *12*(3), 481-496.
[21] Guerra, F., Gainza, F., Pérez, R., & Zamudio, F. (2011). Phytoremediation of heavy metals using poplars (Populus spp.): a glimpse of the plant responses to copper, cadmium and zinc stress. *Handbook of phytoremediation. Nova Science, New York*, 387-413.
[22] Gupta, P., Rani, R., Usmani, Z., Chandra, A., & Kumar, V. (2019). The Role of Plant-Associated Bacteria in Phytoremediation of Trace Metals in Contaminated Soils. In *New and Future Developments in Microbial Biotechnology and Bioengineering* (pp. 69-76). Elsevier.
[23] Henry, J. R. (2000). Prepared by Jeanna R. Henry National Network of Environmental Management Studies (NNEMS) Fellow May-August 2000.
[24] Kabata-Pendias, A., & Pendias, H. (2001). Trace elements in soils and plants, 3rd edn CRC Press. *Boca Raton, FL, USA*.
[25] Kamath, R., Rentz, J. A., Schnoor, J. L., & Alvarez, P. J. J. (2004). Phytoremediation of hydrocarbon-contaminated soils: principles and applications. In *Studies in surface science and catalysis* (Vol. 151, pp. 447-478). Elsevier.
[26] King, D. J., Doronila, A. I., Feenstra, C., Baker, A. J., & Woodrow, I. E. (2008). Phytostabilisation of arsenical gold mine tailings using four Eucalyptus species: growth, arsenic uptake and availability after five years. *Science of the total environment*, *406*(1-2), 35-42.
[27] Knox, A. S. (1999). Gamerdinger, AP, Adriano, DC, Kolka, RK, and Kaplan, DI, Sources and practices contributing to soil contamination. *Bioremediation of Contaminated Soils, Am. Soc.*
[28] Krämer, U. (2010). Metal hyper accumulation in plants. *Annual review of plant biology*, *61*, 517-534.
[29] Kumpiene, J., Lagerkvist, A., & Maurice, C. (2008). Stabilization of as, Cr, Cu, Pb and Zn in soil using amendments–a review. *Waste management*, *28*(1), 215-225.
[30] Lindqvist, O., Johansson, K., Bringmark, L., Timm, B., Aastrup, M., Andersson, A., & Meili, M. (1991). Mercury in the Swedish environment-recent research on causes, consequences and corrective methods. *Water, Air, and Soil Pollution*, *55*(1-2), xi-261.
[31] Liu, D., Jiang, W., Liu, C., Xin, C., & Hou, W. (2000). Uptake and accumulation of lead by roots, hypocotyls and shoots of Indian mustard [Brassica juncea (L.)]. *Bioresource Technology*, *71*(3), 273-277.
[32] Liu, Y. (2006). Shrinking arable lands jeopardizing China's food security. *Worldwatch Institute, April*, *18*.
[33] Lone MI, He ZL, Stoffella PJ, Yang XE. Phytoremediation of heavy metal polluted soils and water: progresses and perspectives. *J Zhejiang Univ Sci B*. 2008;9(3):210–220.
[34] McGrath, S. P., Zhao, F. J., & Lombi, E. (2001). Plant and rhizosphere processes involved in phytoremediation of metal-contaminated soils. *Plant and soil*, *232*(1-2), 207-214.
[35] Mok, H. F., Majumder, R., Laidlaw, W. S., Gregory, D., Baker, A. J., & Arndt, S. K. (2013). Native Australian species are effective in extracting multiple heavy metals from biosolids. *International journal of phytoremediation*, *15*(7), 615-632.
[36] Mosseler, A., & Major, J. (2017). Phytoremediation Efficacy of Salix discolor and S. eriocephela on Adjacent Acidic Clay and Shale Overburden on a Former Mine Site: Growth, Soil, and Foliage Traits. *Forests*, *8*(12), 475.

[37] Negri, M. C., Hinchman, R. R., & Gatliff, E. G. (1996). *Phytoremediation: using green plants to clean up contaminate soil, groundwater, and wastewater* (No. ANL/ES/CP-89941; CONF-960804-38). Argonne National Lab., IL (United States).

[38] Newman, L.A.; Strand, S. E.; Domroes, D.; Duffy, J.; Ekuan, G.; Karscig, G.; Muiznieks, I. A.; Ruszaj, M.; Heilman, P.; Gordon, M.P. (1997) Abstract: Removal of Trichloreth-ylene from a Simulated Aquifer Using Poplar. Fourth International in Situ and On-Site Bioremediation Symposium, April 28 - May 1, 1997, New Orleans, LA. 3: 321.

[39] Nriagu, J. O., & Azcue, J. M. (1994). *Arsenic in the environment. Part I: cycling and characterization* (Vol. 26, pp. 119-132). New York, NY.: John Wiley & Sons.

[40] Ojuederie, O., & Babalola, O. (2017). Microbial and plant-assisted bioremediation of heavy metal polluted environments: A review. *International journal of environmental research and public health*, *14*(12), 1504.

[41] Pavel, L. V., & Gavrilescu, M. (2008). Overview of ex situ decontamination techniques for soil cleanup. *Environmental Engineering & Management Journal (EEMJ)*, *7*(6).

[42] Paz-Alberto, A. M., & Sigua, G. C. (2013). Phytoremediation: a green technology to remove environmental pollutants. *American Journal of Climate Change*, *2*(01), 71.

[43] Peuke, A. D., & Rennenberg, H. (2005). Phytoremediation. *EMBO reports*, *6*(6), 497-501.8. Lucian Vasile Pavel Maria Gavrilescu (2008)

[44] Prasad, M. N. V. (2004). Phytoremediation of metals in the environment for sustainable development. *Proceedings-Indian National Science Academy Part B*, *70*(1), 71-98.

[45] Ragnarsdottir, K. V., & Hawkins, D. (2005). Trace metals in soils and their relationship with scrapie occurrance. *Geochimica et Cosmochimica Acta Supplement*, *69*, A196.

[46] Rakhshaee, R., Giahi, M., & Pourahmad, A. (2009). Studying effect of cell wall's carboxyl–carboxylate ratio change of Lemna minor to remove heavy metals from aqueous solution. *Journal of Hazardous Materials*, *163*(1), 165-173.

[47] Raskin, I., & Ensley, B. D. (2000). *Phytoremediation of toxic metals*. John Wiley and Sons.

[48] rew, A. (2007). Phytoremediation: an environmentally sound technology for pollution prevention, control and remediation in developing countries. *Educational Research and Reviews*, *2*(7), 151-156.

[49] Rew, A. (2007). Phytoremediation: an environmentally sound technology for pollution prevention, control and remediation in developing countries. *Educational Research and Reviews*, *2*(7), 151-156.

[50] Sharma, A., Kaswan, V., & Kaushik, A. (2018). Bioremedition and Phyto–remidiation. *Journal of Pharmacognosy and Phytochemistry*, *7*(1), 723-726.

[51] Shukla, K. P., Sharma, S., Singh, N. K., Singh, V., Bisht, S., & Kumar, V. (2013). Rhizoremediation: a promising rhizosphere technology. In *Applied Bioremediation-Active and Passive Approaches*. IntechOpen.

[52] Tangahu, B. V., Abdullah, S., Rozaimah, S., Basri, H., Idris, M., Anuar, N., & Mukhlisin, M. (2011). A review on heavy metals (As, Pb, and Hg) uptake by plants through phytoremediation. *International Journal of Chemical Engineering*, *2011*.

[53] Tangahu, B. V., Abdullah, S., Rozaimah, S., Basri, H., Idris, M., Anuar, N., & Mukhlisin, M. (2011). A review on heavy metals (As, Pb, and Hg) uptake by plants through phytoremediation. *International Journal of Chemical Engineering*, *2011*

[54] Tangahu, Bieby Voijant, Siti Rozaimah Sheikh Abdullah, Hassan Basri, Mushrifah Idris, Nurina Anuar, and Muhammad Mukhlisin. 2011. "A Review on Heavy Metals (As, Pb, and Hg) Uptake by Plants through Phytoremediation." *International Journal of Chemical Engineering*

[55] Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., & Sutton, D. J. (2012). Heavy metal toxicity and the environment. In *Molecular, clinical and environmental toxicology* (pp. 133-164). Springer, Basel.

[56] Trapp, S., Köhler, A., Larsen, L. C., Zambrano, K. C., & Karlson, U. (2001). Phytotoxicity of fresh and weathered diesel and gasoline to willow and poplar trees. *Journal of soils and sediments*, *1*(2), 71-76.

[57] U.S. EPA. 2000. Introduction to Phytoremediation. EPA/600/ R-99/107. Office of Research and Development, Washington, DC. February 2000.

[58] Van Ginneken, L., Meers, E., Guisson, R., Ruttens, A., Elst, K., Tack, F. M., & Dejonghe, W. (2007). Phytoremediation for heavy metal-contaminated soils combined with bioenergy production. *Journal of Environmental Engineering and Landscape Management*, *15*(4), 227-236.

[59] Walsh, P. R., Duce, R. A., & Fasching, J. L. (1979). Considerations of the enrichment, sources, and flux of arsenic in the troposphere. *Journal of Geophysical Research: Oceans*, *84*(C4), 1719-1726.

[60] Wani, B. A., Khan, A., & Bodha, R. H. (2011). Salix: A viable option for phytoremediation. *African Journal of Environmental Science and Technology*, *5*(8), 567-571.

[61] Wenzel, W. W., Bunkowski, M., Puschenreiter, M., & Horak, O. (2003). Rhizosphere characteristics of indigenously growing nickel hyperaccumulator and excluder plants on serpentine soil. *Environmental Pollution*, *123*(1), 131-138.

[62] Wuana, R. A., & Okieimen, F. E. (2011). Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation. *Isrn Ecology*, *2011*.

[63] Wuana, R. A., & Okieimen, F. E. (2011). Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation. *Isrn Ecology*, *2011*

[64] Xiaomei, L., Qitang, W., & Banks, M. K. (2005). Effect of simultaneous establishment of Sedum alfredii and Zea mays on heavy metal accumulation in plants. *International Journal of Phytoremediation*, *7*(1), 43-53.