An Environmental Remediation: Approach for Clean and Eco-Friendly Renewable Energy

Zulfiqar Ali Ramzan[1], Atif Sardar Khan[1], Wahad Ur Rahman[2], Sadaf Sardar[2], Farid Ullah Khan[2]

[1] U.S.-Pakistan Center for Advanced Studies in Energy, University of Engineering and Technology, Peshawar, Pakistan

[2] Department of Mechatronics, University of Engineering and Technology, Peshawar, Pakistan

Abstract: Uneven weather patterns, rising sea levels and increase in global temperature are due to an increase in emissions harmful to the environment. This calls for technologies and strategies to be used as mitigation measures. To this, phytoremediation, with its different mechanisms, is one way in which we can reduce global emissions. It is a technology that uses different mechanisms for specific plants for the removal of specific pollutants. It is an efficient and environmental friendly process. Despite the limitations of its long development time, site specificity, and climate conditions dependent, this technology can be used to remove contaminants from soil, water and air. In addition, its efficiency can be further improved by certain aids or amendments such as natural, synthetic, microbial and genetically modified plants. This review aims to define the mechanisms and plants involved in phytoremediation while also describing the role of natural and synthetic amendments that can further improve the efficiency of phytoremediation.

Keywords: Phytoremediation; strategies; plants; amendments; environmental friendly.

Introduction

Global warming due to increased emissions mainly carbon emissions are changing the climate around the world which is resulting in uneven weather patterns, rising sea levels, increase in temperature among others. While most of the developed countries are shifting towards renewable sources for their energy demand, others, mostly developing countries are finding it difficult to shift from non-renewable energy sources to renewable energy sources due to several reasons. Moreover, research is continuously carried out to find ways to reduce emissions such as afforestation, carbon capture storage technology, generating electricity from renewable sources such as wind, solar, geothermal besides hydropower. To this, an introduction of a new technology, Phytoremediation, which uses specific plants to remove pollutants from soil, water and air is one which is economically viable and also environmental friendly. It uses different mechanisms such as: degradation which can be rhizo- or phyto-degradation; accumulation: phytoextraction, rhizofiltration; immobilization: includes phytostabilization and hydraulic control; and dissipation: that is, phytovoaltilization; which can degrade, accumulate, remove or immobilize the pollutants.(Pivetz, 2001) Furthermore, there are different plants that use different mechanisms to improve soil and water quality, different approaches can be employed, depending on the specific contaminants present. Their form and the medium in which the pollutants are residing. Ideal plants that are suitable for phytoremediation should have high biomass production, tolerance towards metals and other pollutants, capacity to absorb must be high, and are non-attractive towards herbivores (Adesodun et al., 2010, Sakaki et al., 2011, Shabani, 2012). However, in most of the cases plants used for phytoremediation may not perform well and would require aid to enhance phytoremediation process. Such amendments can be natural, synthetic, microbial and genetically modified plants.

Table 1: Emission of carbon dioxide of energy sources

Renewable energy generation sources	**Emissions of CO_2 (gCO_2eq/kWh)**		**Non-Renewable energy generation sources**	**Emissions of CO_2 (gCO_2eq/kWh)**		**Ref.**
Hydro	20[1]	10[2]	Natural gas	600[1]	430[2]	(Cucchiella et al., 2017)[1]
Wind	30[1]	10[2]	Oil	820[1]	790[2]	(Bakhtyar et al., 2017)[2]
Solar	200[1]	40[2]	Coal	1190[1]	1050[2]	
Geothermal	50[1]	40[2]				
Nuclear	80[1]	70[2]				

Table 2: Heavy Metal pollution sources (Arora and Khosla, 2022)

Sources of Agrochemicals	Urban Emissions	Industrial Emissions	Atmospheric Emissions	Incidental Emissions
Chemical Fertilizers, Organic Fertilizers, and Pesticides	Electric Generating Stations, Ash Settling	Mining and Metal Refining	Dispersed pollutants due to wind	Warfare munitions, noxious fumes
Fuel Leakage	Transportation Fuel, Combustion Byproducts, Acidic Depositions	Metallurgical Sectors	Acidic Settling	Industrial Mishaps

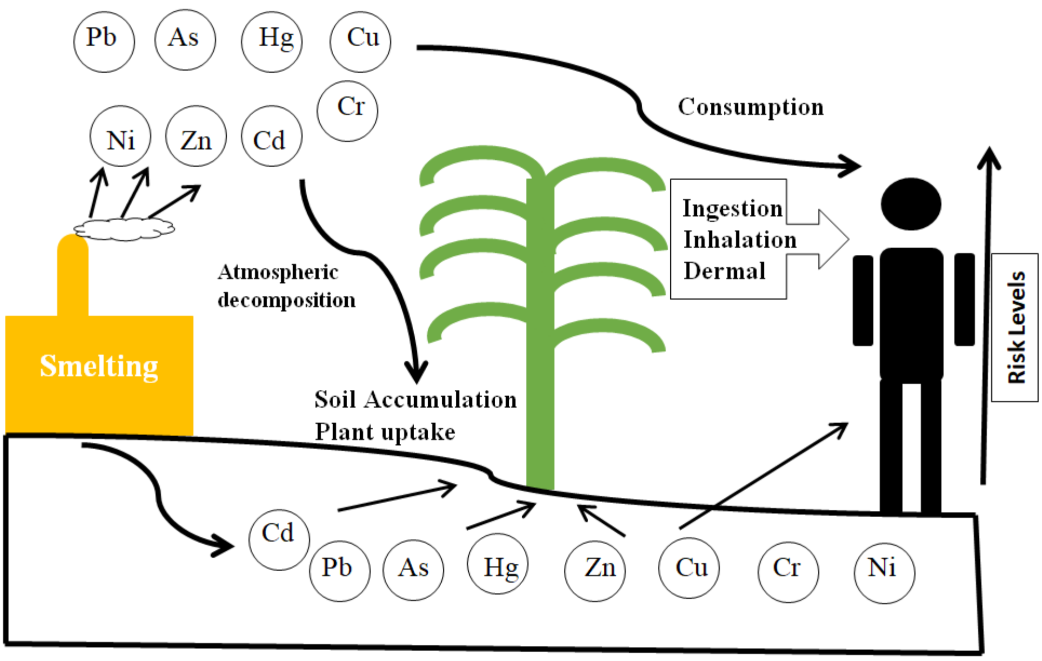

Figure 1: Release of heavy metals and their dominant exposure and possible uptake routes to humans

Phytoremediation Mechanisms and plants selection

Different plants can be used for different phytoremediation mechanisms for removing contaminants from water, soil and air. Moreover, plants interact with their surroundings plays an important role in eliminating pollutants (Dary et al., 2010). The improvement, thus, is dependent on the contaminant type. Additionally, the plant type used for removal of the contaminant, and also the type of soil. According to (Wu et al., 2011), the potential of plants to use phytoremediation is evaluated using the Bio concentration Factor (BCF), the pollutant concentration ratio in various parts of a plant compared to the concentration in the medium, and Translocation factor (TF) is the ratio of a pollutant accumulation in a plant's shoot compared to the plant's root potential of accumulation.

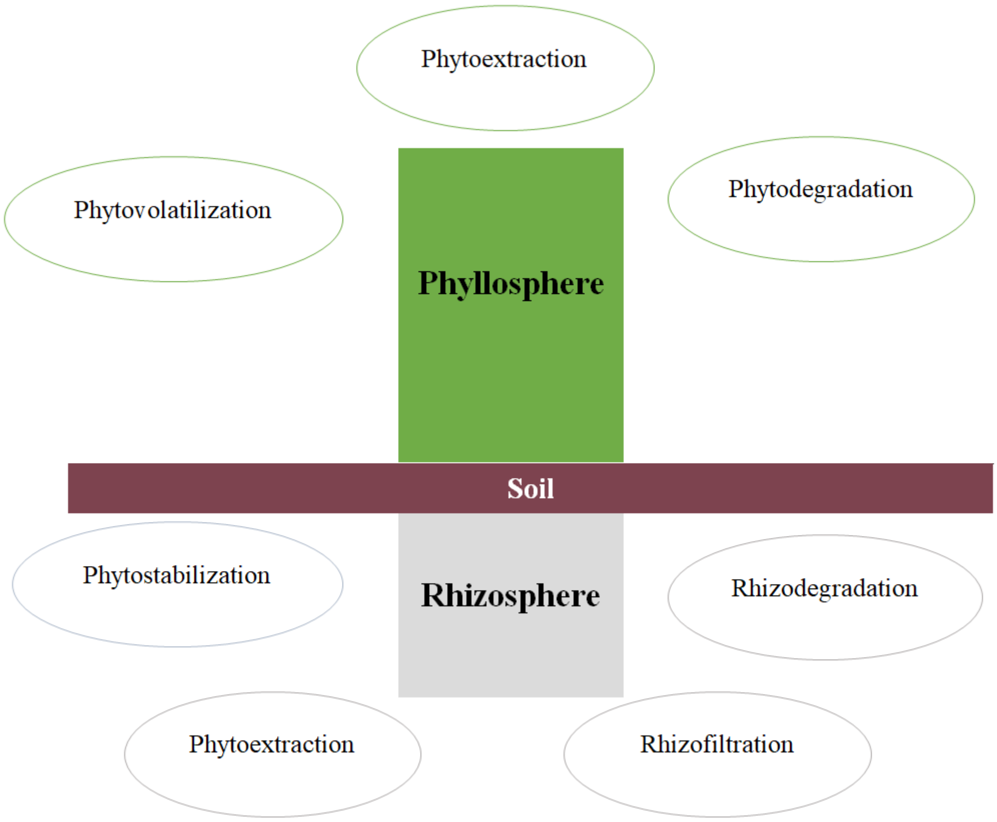

Figure 2: Techniques used by phytoremediation in phyllosphere and rhizosphere

Phytoextraction

It involves both, phyllosphere and rhizosphere as shown in Fig 1, of plants and extracts soil and transports contaminants to the parts of plants above the ground. Plants with high biomass production and those that can be easily harvested are selected. For instance, Rattle bush, Indian mustard, corn (Barlow et al., 2000),(Salido et al., 2003),(Huang et al., 2019) can be used to remove contaminants such as Lead (Pb) where chelating agent such as EDTA (ethylene diamine tetra-acetate) is applied to that plants soil which mobilizes lead and facilitates its extraction. Other plants that have high absorption capacity and lower intrinsic velocity such as lettuce, perennial rye grass (Hernández et al., 2019) can be used for contaminants such as nickel (Ni), Cobalt (Co), and Iron (Fe).

Phytostabilization/Phytoimmobilization

Immobilization of contaminants is carried out in rhizosphere part of the plant reduces contaminants the migration. In this case, the lignin found in the cell walls of roots of plants acts like an absorbent, drying contaminants. It then transforms them into insoluble compounds, which get stored in the rhizosphere. The process reduces the harmful effects of the contaminants.

For instance, Sunflower (Jadia and Fulekar, 2008) usually for low levels of contaminants such as Copper, zinc, lead, mercury, arsenic, cadmium, and nickel, can be used. Another plant, black nightshade (Li et al., 2019) with ten percent Biochar addition can be used for contaminants such as copper, zinc and cadmium.

Rhizofiltration

The plant roots have a potential to dry and filter out pollutants from water using the rhizosphere. This mechanism is commonly used from groundwater, wastewater, and for remediation of surface water. Here, plant that are selected has compulsion to have absorption of high surface area, high tolerance and root biomass towards contaminants. For instance, Carolina mosquito fern/ water velvet (Favas et al., 2012) can be used against arsenic contaminants. Sunflower and mustard can filter water contaminated with lead through precipitating in roots (i.e. lead and phosphate). (Dushenkov et al., 1995)

Phytovolatilization

In this mechanism, the diffused pollutants in the plant (phyllosphere part) are transformed into volatile compounds. The benefit of the mechanism is that the level of toxicity of pollutants could potentially be reduced before their release into the air. Willow plant (Gordon et al., 1998) which has huge biomass and the ability to use different phytoremediation mechanisms can be used for pollutants such as trichloroethylene (TCE) and tetrachloroethylene (PCE). These contaminants can also be removed using hybrid poplar tree(Gordon et al., 1998).

Phytodegradation

It is also called as phytotransformation as contaminants are transformed by plants and are incorporated into plant tissues in phyllosphere part of the plants. It degrades complex organic pollutants to simple and less harmful compounds. For instance, unicellular green algae (Headley et al., 2008)can be used against contaminant such as Pentachlorophenol (PCP). The reduction dehalogenation of Dichlorodiphenyltrichloroethane (DDT) can be carried out by the use of aquatic plants (Garrison et al., 2000).

Rhizodegradation

It is also called as phytostimulation and in this mechanism degradation process of contaminants occur in rhizosphere part of the plant and the process is stimulated by rhizosphere microorganisms. For instance, using Bermuda grass (Matsodoum Nguemté et al., 2018) petroleum hydrocarbons in total had a degradation of 81 %. Mangrove (Lu et al., 2011) used against contaminants such as Phenathrene (Ph) and Pyrene (Py) showed dissipation of 47.7 % and 37.6 % respectively in rhizosphere.

Role of Amendments

While phytoremediation technology can remove contaminants, however, for improving this technology performance, certain aids or amendments such as natural, synthetic, microbes, and genetically modified plants can be carried out. The amendments in soil enhances the effectiveness of phytoremediation by improving the resistance capability of plants, their level of tolerance towards contaminants, and also enhancing translocation and accumulation of the contaminants. Here, natural and synthetic amendments are discussed.

Natural Amendments

These are naturally produced materials that are used to improve the overall efficiency of phytoremediation. Some of the natural amendments are discussed below

Sugar beet residue (SBR) which is produced as a result of sugar extraction can enhance plant growth and phytoextraction process when treated with Aspergillus Niger, soil amendments contain a blend of phosphate and polysaccharides, which are specially designed to enhance the effectiveness of phytoremediation. (Azcón et al., 2009), (Medina et al., 2006). when SBR is incorporated into various plants (Azcón et al., 2009) (Medina et al., 2006) and sea fennel (Fernández et al., 2012) resulted in the enhancement of phytoextraction for different heavy metals such as Nickel, Zinc, Iron, Boron, Chromium, and Cadmium.

Another natural amendment is composed of sludge from sewage, an industrial by product, which can be used for soil amendment, providing a useful resource for soil quality fertility and enhancement. Using the phytoextraction mechanism by sunflower and applying sewage sludge (Liphadzi and Kirkham, 2006) on Cadmium and Nickel increased their metal bioavailability.

In addition, applying paper waste (Doichinova and Velizarova, 2013) on seedlings of red oak and Austrian pine tree reduced the uptake of lead and cadmium.

Moreover, Biochar is another soil amendment, which is made through the process of pyrolysis of crop and animal residue. Rich in carbon content and having high surface area as well as high cation exchange properties, Biochar is reported for reducing metal bioavailability as well as its phytotoxicity. For example, applying wood Biochar (Namgay et al., 2010) reduces content of arsenic, cadmium, concentration of copper in corn shoots and the concentration of lead in the soil lead content in the soil. In addition, the concentration of copper and lead were reduced in plant shoots by 46 % and 71 % when Biochar of bamboo and rice straw (Lu et al., 2014) were applied to Sedum Plubizincicola which increased its biomass content.

Synthetic Amendments

Another amendment used for improving efficiency of phytoremediation is synthetic or chemical amendment which facilitates the uptake of heavy metals and their translocation in plants. Among the several chemical amendments, Ethylene Diamine Tetra Acetic acid (EDTA), Ethyl Glycol Tetra Acetic acid (EGTA) and Sodium Dodecyl Sulfate (SDS) are chelating agents most used. And among them, EDTA has been considered as most effective chemical in phytoextraction process.

The use of EDTA can be mostly seen in agriculture due to the role played by it in mobilization of heavy metals. For instance, corn grown under hydroponic conditions, the use of EDTA (Zhao et al., 2010)enhanced uptake of lead by six to seven times compared to that without EDTA. Moreover, the application of EDTA increased an accumulation of lead in the root system of Sedum Alfredii (Sun et al., 2009) seedlings of broad bean (Shahid et al., 2014).

Another widely used chelating agent, EGTA, is also found for its increased metal uptake and its accumulation. In a study, after applying EGTA on above ground parts of chickpea plants (Sakouhi et al., 2016) resulted in an increased accumulation of lead. Also, after the application of EGTA on Hollyhock (Liu et al., 2008)Marvel-of-Peru plant(Wang and Liu, 2014), there were higher concentration of cadmium found.

SDS is mostly used for remediation of contamination in the soil. Heavy metals solubility such as copper, zinc, lead and cadmium can be increased by applying this surfactant. For instance, applying SDS on hollyhock plant (Liu et al., 2009) there was experienced an increase of cadmium accumulation in its roots and shoots. Also, cadmium accumulation was also promoted in shoots of pot marigold plant (Liu et al., 2010) after the surfactant was applied.

Analysis of Natural and Synthetic amendments

For natural amendment such as by applying SBR, it had an increased phytoextraction efficiency. This was due to an increase in the microbial biomass in the rhizosphere part of the plant. In addition, microbes helped in reducing metals hence increasing the bioavailability of metals (Medina et al., 2006, Azcón et al., 2009). Moreover, Biochar, another natural amendment, can be beneficial in soil if accompanied by an increase of absorption sites, capacity to hold water, and cycling the nutrients. However, Biochar use can be harmful in that, it is made through the process of pyrolysis which can be harmful for the environment causing air pollution. (Mara dos Santos Barbosa et al., 2006)

Meanwhile, chemical amendments do increase the efficiency of phytoremediation process. However, chelating agents are toxic to microbes present in soil (Mühlbachová, 2011) activities of enzymes, and plant species (Neugschwandtner et al., 2012). As chelating agents have poor biodegradability, they can remain in the soil for an indefinite amount of time that may lead to leaching of metals while also environment is adversely affected. (Lee et al., 2014, Smolińska et al., 2012). To this, if chemical amendments are to be used, they must be applied in an optimum level in order to limit their adverse effect on the environment.

Conclusion

Phytoremediation is a sustainable technology as it is cost-effective as well as environmental friendly for the remediation of pollutants in soil, water, and also air. The selection of plants for specific contaminants and the mechanisms through which contaminants can be removed by using specific plants are some of the defining characteristics of phytoremediation. While there are still some limitations for full-scale use of phytoremediation for prolong time, climate and plant growth dependent, and to overcome the design properly while also selecting proper species of plants. Another concern is low efficiency of phytoremediation. However, with aids or amendments such as natural and synthetic discussed above, can improve the mechanisms involved as well as help in plant growth. To conclude, for the changing climate due to global warming, it is time to use such technologies that can help in reduction of pollutants in soil, water and air, while also aiming for sustainable growth, because what is at stake is nothing less than the future of planet earth.

References

Adesodun, J.K., Atayese, M.O., Agbaje, T.A., Osadiaye, B.A., Mafe, O.F., Soretire, A.A., 2010. Phytoremediation Potentials of Sunflowers (Tithonia diversifolia and Helianthus annuus) for Metals in Soils Contaminated with Zinc and Lead Nitrates. Water. Air. Soil Pollut. 207, 195–201. https://doi.org/10.1007/s11270-009-0128-3

Arora, V., Khosla, B., 2022. Conventional and Contemporary Techniques for Removal of Heavy Metals from Soil. https://doi.org/10.5772/intechopen.98569

Azcón, R., Medina, A., Roldán, A., Biró, B., Vivas, A., 2009. Significance of treated agrowaste residue and autochthonous inoculates (Arbuscular mycorrhizal fungi and Bacillus cereus) on bacterial community structure and phytoextraction to remediate soils contaminated with heavy metals. Chemosphere 75, 327–334. https://doi.org/10.1016/j.chemosphere.2008.12.029

Bakhtyar, B., Fudholi, A., Hassan, K., Azam, M., Lim, C.H., Chan, N.W., Sopian, K., 2017. Review of CO2 price in Europe using feed-in tariff rates. Renew. Sustain. Energy Rev. 69, 685–691.

Barlow, R., Bryant, N., Andersland, J., Sahi, S., 2000. LEAD HYPERACCUMULATION BY 3.

Cucchiella, F., D'Adamo, I., Gastaldi, M., 2017. Economic Analysis of a Photovoltaic System: A Resource for Residential Households. Energies 10, 814. https://doi.org/10.3390/en10060814

Dary, M., Chamber-Pérez, M.A., Palomares, A.J., Pajuelo, E., 2010. "In situ" phytostabilisation of heavy metal polluted soils using Lupinus luteus inoculated with metal resistant plant-growth promoting rhizobacteria. J. Hazard. Mater. 177, 323–330. https://doi.org/10.1016/j.jhazmat.2009.12.035

Doichinova, V., Velizarova, E., 2013. Reuse of Paper Industry Wastes as Additives in Phytoremediation of Heavy Metals Polluted Substrates from the Spoil Banks of the Kremikovtsi Region, Bulgaria. Procedia Environ. Sci., 2013 International Symposium on Environmental Science and Technology (2013 ISEST) 18, 731–736. https://doi.org/10.1016/j.proenv.2013.04.099

Dushenkov, Viatcheslav., Kumar, P.B.A.Nanda., Motto, Harry., Raskin, Ilya., 1995. Rhizofiltration: The Use of Plants to Remove Heavy Metals from Aqueous Streams. Environ. Sci. Technol. 29, 1239–1245. https://doi.org/10.1021/es00005a015

Favas, P.J.C., Pratas, J., Prasad, M.N.V., 2012. Accumulation of arsenic by aquatic plants in large-scale field conditions: Opportunities for phytoremediation and bioindication. Sci. Total Environ. 433, 390–397. https://doi.org/10.1016/j.scitotenv.2012.06.091

Fernández, D.A., Roldán, A., Azcón, R., Caravaca, F., Bååth, E., 2012. Effects of Water Stress, Organic Amendment and Mycorrhizal Inoculation on Soil Microbial Community Structure and Activity During the Establishment of Two Heavy Metal-Tolerant Native Plant Species. Microb. Ecol. 63, 794–803. https://doi.org/10.1007/s00248-011-9972-y

Garrison, A.W., Nzengung, V.A., Avants, J.K., Ellington, J.J., Jones, W.J., Rennels, D., Wolfe, N.L., 2000. Phytodegradation of p,p'-DDT and the Enantiomers of o,p'-DDT. Environ. Sci. Technol. 34, 1663–1670. https://doi.org/10.1021/es990265h

Gordon, M., Choe, N., Duffy, J., Ekuan, G., Heilman, P., Muiznieks, I., Ruszaj, M., Shurtleff, B.B., Strand, S., Wilmoth, J., Newman, L.A., 1998. Phytoremediation of trichloroethylene with hybrid poplars. Environ. Health Perspect. 106, 1001–1004.

Headley, J.V., Peru, K.M., Du, J.-L., Gurprasad, N., Mcmartin, D.W., 2008. Evaluation of the apparent phytodegradation of pentachlorophenol by *Chlorella pyrenoidosa*. J. Environ. Sci. Health Part A 43, 361–364. https://doi.org/10.1080/10934520701795491

Hernández, A., Loera, N., Contreras, M., Fischer, L., Sánchez, D., 2019. Comparison Between Lactuca sativa L. and Lolium perenne: Phytoextraction Capacity of Ni, Fe, and Co from Galvanoplastic Industry, in: Wang, T., Chen, X., Guillen, D.P., Zhang, L., Sun, Z., Wang, C., Haque, N., Howarter, J.A., Neelameggham, N.R., Ikhmayies, S., Smith, Y.R., Tafaghodi, L., Pandey, A. (Eds.), Energy Technology 2019, The Minerals, Metals & Materials Series. Springer International Publishing, Cham, pp. 137–147. https://doi.org/10.1007/978-3-030-06209-5_14

Huang, X., Luo, D., Chen, X., Wei, L., Liu, Y., Wu, Q., Xiao, T., Mai, X., Liu, G., Liu, L., 2019. Insights into Heavy Metals Leakage in Chelator-Induced Phytoextraction of Pb- and Tl-Contaminated Soil. Int. J. Environ. Res. Public. Health 16, 1328. https://doi.org/10.3390/ijerph16081328

Jadia, C.D., Fulekar, M.H., 2008. Phytoremediation: The application of vermicompost to remove zinc, cadmium, copper, nickel and lead by sunflower plant. Environ. Eng. Manag. J. EEMJ 7.

Lee, J., Sung, K., 2014. Effects of chelates on soil microbial properties, plant growth and heavy metal accumulation in plants. Ecol. Eng. 73, 386–394. https://doi.org/10.1016/j.ecoleng.2014.09.053

Li, X., Zhang, X., Wang, X., Cui, Z., 2019. Phytoremediation of multi-metal contaminated mine tailings with Solanum nigrum L. and biochar/attapulgite amendments. Ecotoxicol. Environ. Saf. 180, 517–525. https://doi.org/10.1016/j.ecoenv.2019.05.033

Liphadzi, M.S., Kirkham, M.B., 2006. Chelate-Assisted Heavy Metal Removal by Sunflower to Improve Soil with Sludge. J. Crop Improv. 16, 153–172. https://doi.org/10.1300/J411v16n01_11

Liu, J., Zhou, Q., Wang, S., 2010. Evaluation of Chemical Enhancement on Phytoremediation Effect of Cd-Contaminated Soils with Calendula Officinalis L. Int. J. Phytoremediation 12, 503–515. https://doi.org/10.1080/15226510903353112

Liu, J.-N., Zhou, Q.-X., Sun, T., Ma, L.Q., Wang, S., 2008. Identification and Chemical Enhancement of Two Ornamental Plants for Phytoremediation. Bull. Environ. Contam. Toxicol. 80, 260–265. https://doi.org/10.1007/s00128-008-9357-1

Liu, J.N., Zhou, Q.X., Wang, S., Sun, T., 2009. Cadmium tolerance and accumulation of Althaea rosea Cav. and its potential as a hyperaccumulator under chemical enhancement. Environ. Monit. Assess. 149, 419–427. https://doi.org/10.1007/s10661-008-0218-5

Lu, H., Li, Z., Fu, S., Méndez, A., Gascó, G., Paz-Ferreiro, J., 2014. Can Biochar and Phytoextractors Be Jointly Used for Cadmium Remediation? PLOS ONE 9, e95218. https://doi.org/10.1371/journal.pone.0095218

Lu, H., Zhang, Y., Liu, B., Liu, J., Ye, J., Yan, C., 2011. Rhizodegradation gradients of phenanthrene and pyrene in sediment of mangrove (Kandelia candel (L.) Druce). J. Hazard. Mater. 196, 263–269. https://doi.org/10.1016/j.jhazmat.2011.09.031

Mara dos Santos Barbosa, J., Ré-Poppi, N., Santiago-Silva, M., 2006. Polycyclic aromatic hydrocarbons from wood pyrolyis in charcoal production furnaces. Environ. Res. 101, 304–311. https://doi.org/10.1016/j.envres.2006.01.005

Matsodoum Nguemté, P., Djumyom Wafo, G.V., Djocgoue, P.F., Kengne Noumsi, I.M., Wanko Ngnien, A., 2018. Potentialities of Six Plant Species on Phytoremediation Attempts of Fuel Oil-Contaminated Soils. Water. Air. Soil Pollut. 229, 88. https://doi.org/10.1007/s11270-018-3738-9

Medina, A., Vassileva, M., Barea, J.-M., Azcón, R., 2006. The growth-enhancement of clover by Aspergillus-treated sugar beet waste and Glomus mosseae inoculation in Zn contaminated soil. Appl. Soil Ecol. 33, 87–98. https://doi.org/10.1016/j.apsoil.2005.08.003

Mühlbachová, G., 2011. Soil microbial activities and heavy metal mobility in long-term contaminated soils after addition of EDTA and EDDS. Ecol. Eng., Biogeochemical aspects of ecosystem restoration and rehabilitation 37, 1064–1071. https://doi.org/10.1016/j.ecoleng.2010.08.004

Namgay, T., Singh, B., Singh, B.P., 2010. Influence of biochar application to soil on the availability of As, Cd, Cu, Pb, and Zn to maize (Zea mays L.). Aust. J. Soil Res.

Neugschwandtner, R.W., Tlustoš, P., Komárek, M., Száková, J., Jakoubková, L., 2012. Chemically Enhanced Phytoextraction of Risk Elements from a Contaminated Agricultural Soil Using Zea Mays and Triticum Aestivum: Performance and Metal Mobilization Over a Three Year Period. Int. J. Phytoremediation 14, 754–771. https://doi.org/10.1080/15226514.2011.619231

Pivetz, B.E., 2001. Phytoremediation of contaminated soil and ground water at hazardous waste sites. US Environmental Protection Agency, Office of Research and Development ….

Sakakibara, M., Ohmori, Y., Ha, N.T.H., Sano, S., Sera, K., 2011. Phytoremediation of heavy metal-contaminated water and sediment by Eleocharis acicularis. CLEAN – Soil Air Water 39, 735–741.

Sakouhi, L., Rahoui, S., Ben Massoud, M., Munemasa, S., EL Ferjani, E., Murata, Y., Chaoui, A., 2016. Calcium and EGTA Alleviate Cadmium Toxicity in Germinating Chickpea Seeds. J. Plant Growth Regul. 35, 1064–1073. https://doi.org/10.1007/s00344-016-9605-2

Salido, A.L., Hasty, K.L., Lim, J.-M., Butcher, D.J., 2003. Phytoremediation of Arsenic and Lead in Contaminated Soil Using Chinese Brake Ferns (*Pteris vittata*) and Indian Mustard (*Brassica juncea*). Int. J. Phytoremediation 5, 89–103. https://doi.org/10.1080/713610173

Shabani, N., Sayadi, M.H., 2012. Evaluation of heavy metals accumulation by two emergent macrophytes from the polluted soil: an experimental study. The Environmentalist 32, 91–98. https://doi.org/10.1007/s10669-011-9376-z

Shahid, M., Austruy, A., Echevarria, G., Arshad, M., Sanaullah, M., Aslam, M., Nadeem, M., Nasim, W., Dumat, C., 2014. EDTA-Enhanced Phytoremediation of Heavy Metals: A Review. Soil Sediment Contam. Int. J. 23, 389–416. https://doi.org/10.1080/15320383.2014.831029

Smolińska, B., Król, K., 2012. Leaching of mercury during phytoextraction assisted by EDTA, KI and citric acid. J. Chem. Technol. Biotechnol. 87, 1360–1365.

Sun, Y., Zhou, Q., Wang, L., Liu, W., 2009. The Influence of Different Growth Stages and Dosage of EDTA on Cd Uptake and Accumulation in Cd-Hyperaccumulator (Solanum Nigrum L.). Bull. Environ. Contam. Toxicol. 82, 348–353. https://doi.org/10.1007/s00128-008-9592-5

Wang, S., Liu, J., 2014. The effectiveness and risk comparison of EDTA with EGTA in enhancing Cd phytoextraction by Mirabilis jalapa L. Environ. Monit. Assess. 186, 751–759. https://doi.org/10.1007/s10661-013-3414-x

Wu, Q., Wang, S., Thangavel, P., Li, Q., Zheng, H., Bai, J., Qiu, R., 2011. Phytostabilization Potential of Jatropha Curcas L. in Polymetallic Acid Mine Tailings. Int. J. Phytoremediation 13, 788–804. https://doi.org/10.1080/15226514.2010.525562

Zhao, Z., Xi, M., Jiang, G., Liu, X., Bai, Z., Huang, Y., 2010. Effects of IDSA, EDDS and EDTA on heavy metals accumulation in hydroponically grown maize (Zea mays, L.). J. Hazard. Mater. 181, 455–459. https://doi.org/10.1016/j.jhazmat.2010.05.032

First Author – Zulfiqar Ali Ramzan, Postgraduate student,

U.S.-Pakistan Center for Advanced Studies in Energy, University of Engineering and Technology, Peshawar, Pakistan

Second Author – Dr. Atif Sardar Khan, Lecturer, U.S.-Pakistan Center for Advanced Studies in Energy, University of Engineering and Technology, Peshawar, Pakistan

Third Author – Engr. Wahad Ur Rahman, Lab Engineer, Department of Mechatronics, University of Engineering and Technology, Peshawar, Pakistan

Fourth Author – Engr. Sadaf Sardar, Department of Mechatronics, University of Engineering and Technology, Peshawar, Pakistan

Fifth Author – Dr. Farid Ullah Khan, Professor, Department of Mechatronics, University of Engineering and Technology, Peshawar, Pakistan

Correspondence Author – Dr. Atif Sardar Khan