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A review of phytoremediation technology: heavy metals uptake by plants

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Abstract. Heavy metal is one of the serious environmental pollutions for now days as impact of industrial development in several countries. Heavy metals give toxic effects on human health and cause several serious diseases. Several techniques have been using for removing heavy metal contaminants from the environmental but these techniques have limitations such as high cost, long time, logistical problems and mechanical complexity. Phytoremediation can be used as an alternative solution for heavy metal remediation process because of its advantages as a cost-effective, efficient, environment- and eco-friendly technology based on the use of metal-accumulating plants. According to previous studies, several plants have a high potential as heavy metals bioaccumulator and can be used for phytoremediation process of heavy metals.

1. Introduction

Environmental pollution has became a serious public health concern because it becomes a major source of health risk and causes several serious deseases throughout the world [1]. One of the serious environmental pollutions is heavy metals. Although the health effects of heavy metals have been known for a long time, exposure to heavy metals continues and is even increasing in some areas. The effects of heavy metals on human health can even lead to death [2]. The different heavy metal gives different toxic effects on human health as showed by table 1. Environmental pollution by heavy metals have increased as a influence of industrial development and it was shown that many heavy metals in high level was found in industrial areas [3,4,5].

Heavy metals become a primary concern than other environmental pollutions because heavy metals can’t be destroyed by degradation. The remediation process of contaminated soils, groundwater, and surface water by heavy metals needs some methods to remove the metals from contaminated areas [6]. Several methods have being used for removing the pollutants from the contaminated environments. Soils that are contaminated with heavy metals can be treated by acid leaching, soil washing, physical or mechanical separation of the contaminant, electro-chemical treatment, electrokinetics, chemical treatment, thermal or pyrometalurgical separation and biochemical processes [7,8,9,10]. Remediation techniques can be used for removing heavy metals from contaminated ground water are extraction and treatment by activated carbon adsorption, microbes use, air stripping [11], chemical, biological, biochemical and biosorptive treatment technologies [9].

The use of some of these remediation techniques requires a high cost [10,12,13], a long time [11], logistical problems [14] and technical complexity [15]. Therefore alternative sollution is needed for heavy metals removing from the environment. Bioremediation is an innovative and promising technology available for removal of heavy metals and recovery of the heavy metals in polluted water and lands [16].

Table 1. Toxic effects of some heavy metals on human health [16]

Heavy Metal	EPA[a] Regulatory Limit (ppm)	Toxic Effects
Ag	0.10	Exposure may cause skin and other body tissues to turn gray or blue-gray, breathing problems, lung and throat irritation and stomach pain.
As	0.01	Affects essential cellular processes such asoxidative phosphorylation and ATP synthesis
Ba	2.00	Cause cardiac arrhythmias, respiratory failure, gastrointestinal dysfunction, muscle twitching and elevated blood pressure
Cd	5.00	Carcinogenic, mutagenic, endocrine disruptor, lung damage and fragile bones, affects calcium regulation in biological systems
Cr	0.10	Hair loss
Cu	1.30	Brain and kidney damage, elevated levels result in liver cirrhosis and chronic anemia, stomach and intestine irritation
Hg	2.00	Autoimmune diseases, depression, drowsiness, fatigue, hair loss, insomnia, loss of memory, restlessness, disturbance of vision, tremors, temper outbursts, brain damage, lung and kidney failure
Ni	0.20	Allergic skin diseases such as itching, cancer of the lungs, nose, sinuses, throat through continuous inhalation, immunotoxic, neurotoxic, genotoxic, affects fertility, hair loss
Pb	15.00	Excess exposure in children causes impaired development, reduced intelligence, short-term memory loss, disabilities in learning and coordination problems, risk of cardiovascular disease
Se	50.00	Dietary exposure of around 300 μg day^{-1} affects endocrine function, impairment of natural killer cells activity, hepatotoxicity and gastrointestinal disturbaces
Zn	0.50	Dizziness, fatigue etc.

[a]EPA : United State Environmental Protection Agency

Phytoremediation is one of bioremediation techniques can be used as an alternative solution for heavy metal remediation proscess. The phytoremediation of metals is a cost-effective, efficient, environment- and eco-friendly 'green' technology based on the use of metal-accumulating plants to remove toxic metals, including radionuclides as well as organic pollutants from contaminated soils and water [12,15]. The objectives of this review is to give the general information about phytoremediation and use of plants for phytoremediation processes of heavy metals from the environment.

2. Source of heavy metals in the environment

Elements with metallic properties and an atomic number >20 is the conventionally definition of heavy metals. Naturally, metals are normal components in soils. However, in high levels, metals can be toxic for plants, animal and microbes [17]. The most common and important heavy metals as contaminant in the environment are As, Sr, Cs, U [12], Cd, Cr, Cu, Hg, Pb and Zn [12,17]. Some of these metals are micronutrients necessary for plant growth and development, such as Zn, Cu, Mn, Ni, and Co, while others have unknown biological function, such as Cd, Pb, and Hg [18].

Heavy metals in the environment come from natural and anthropogenic (human intervention) sources. Minerals weathering, erosion and volcanic activity are the most significant natural sources while for anthropogenic sources are mining, smelting, electroplating, use of pesticides and fertilizers as well as biosolids in agriculture, sludge dumping, industrial discharge, atmospheric deposition, etc. [15,16]. The anthropogenic sources of several heavy metals in the environment presented in table 2.

Table 2. Anthropogenic sources of several heavy metals in the environment [15]

Heavy Metals	Sources
As	Pesticides and wood preservatives
Cd	Paints and pigments, plastic stabilizers, electroplating of cadmium containing plastics, phosphate fertilizer
Cr	Tanneries, steel industries, fly ash
Cu	Pesticides, fertilizers
Hg	Release from Au-Ag mining and coal combustion, medical waste
Ni	Idustrial effluents, kitchen appliances, surgical instruments, steel alloys, automobile batteries
Pb	Aerial emission from combustion of lead petrol, battery manufacture, herbicides and insecticides

2.1 Phytoremediation and its mechanisms

The term of phytoremediation is relatively new, started from 1991. The term "*phytoremediation*" consists of the Greek prefix *phyto* which is means 'plant' and the Latin root *remedium* which is means 'to correct or remove evil'. Basic information for phytoremediation comes from a variety of research areas including constructed wetlands, oil spills, and agricultural plant accumulation of heavy metals. The term has been used widely since its inception, with a variety of specific meanings [19].

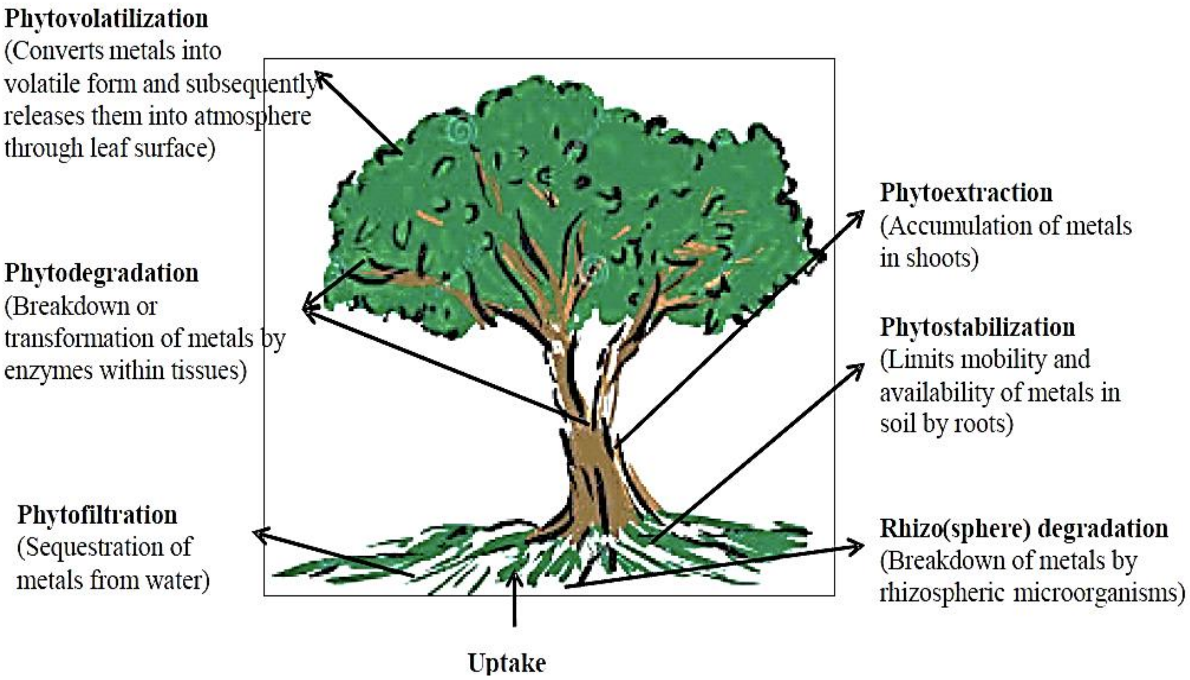

Figure 1. Various mechanisms involved in the phytoremediation of heavy metals [16]

Many definitions of phytoremediation have been given by researchers. According to those definitions, [10] have concluded and made the general definition of phytoremediation as an emerging technology using selected plants to clean up the contaminated environment from hazardous contaminant to improve the environment quality. [19] has said that phytoremediation has been receiving attention lately as an innovative, cost-effective alternative to the more established treatment methods used at hazardous waste sites. [15] have called phytoremediation as 'green technology' because of its advantages as a cost-effective, efficient, environment- and eco-friendly technology.

There are numerous plant mechanisms for remediating heavy metal contaminants from the environment. As it functions to remediate contaminant from soils and water, at least there are six mechanisms of plants on phytoremediation process include phytoextraction, phytofiltration, phytostabilization, phytodegradation, phytovolatilation, rhizodegradation [15,16,19]. The summary of the phytoremediation mechanisms is shown in figure 1.

2.2 Plants heavy metals uptake and responses

Several previous studies have described the potential of plant as heavy metals bioaccumulator from contaminated soil and water. The studies have indicated the use of plants through phytoremediation technology is an alternative solution to treat heavy metal contaminated areas and can be used to remediate the environment. Table 3 summarizes the list of several plants reported for heavy metals remediation. Each different plant has also different responses to different heavy metals exposure. Several plants are sensitive while other plants have a high tolerance to several heavy metals. As a consequence of plant-metal interaction, several plants accumulate heavy metals from soil and have growth and development decreases. However, some plants have a high tolerance and can keep the growth and development as well under heavy metals stress.

Different responses of plants to heavy metals exposure depend on its level of heavy metals tolerance. For examples, Chives plants (*Allium schoenoprasum*) got wilting, yellowing and growth inhibition on Ni, Co and Cd at 0.25 mM consentrations [20]. On chickpea plants (*Cicer auratinum*), Pb and Cr inhibited the seed germination and decreased the dry wight of plants with increase in metal consentrations and time intervals [21]. Cd stress with 20 μM consentration did not significantly affect root dry weight, shoot height, shoot dry weight, leaf number and total chlorophyll concentration (a and b) of pea plant cv. Kelvedon Wonder except root length compared with the plants grown without Cd treatments [22]. The dry weight of maize plant (*Zea mays*) extremely decreased on Zn-amanded soil with increase in Zn doses. At 270 mg kg^{-1} dose of Zn, shoot and root dry matter production of maize was 468% and 250% lower than control, approximately. The presence of Zn also changed chlorophyll a flourescence and antioxidant system parameters [23].

The most important factor affecting the rate of metal removal in phytoremediation is plant selection to be used as accumulator. [17] has described some considerations for the selection of remediating plants:

- The plant biomass, the metal removal rate depends on the plant biomass harvested and metal consentration in harvested biomass.
- Ecosystem protection, native species are preferred to exotic plants, which can be invasive and endanger the harmony of the ecosystem. To avoid propagation of weedy species, crops are in general preferred, although some crops may be too palatable and pose a risk to grazing animals.
- Physical characteristics of soil contamination, for the remediation of surface-contaminated soils, shallowrooted species would be appropriate to use, whereas deep-rooted plants would be the choice for more profound contamination.

Table 3. Several crop plants used to heavy metals phytoremediation studies.

Plants	Contaminated areas	Heavy Metals	References
Allium schoenoprasum L. (Chive)	Soil	Ni, Co, Cd	[20]
Brassica juncea L. (Indian mustard)	Soil and water	Cd, Cu, Zn, Pb	[24,25,26,27,28]
Brassica napus L. (canola)	Soil	Cd, Cu, Zn, Pb	[26,29,30]
Cajanus Cajan (L.) Milsp. (pigeon pea)	Soil	As, Cd	[31]
Cicer aeritinum L. (chickpea)	Soil	Cd, Pb, Cr, Cu	[21,32,33]
Cucumis sativus L. (cucumber)	Water	Pb	[25]
Eichhornia crassipes L. (water hyacinth)	Water	As, Cr, Zn, Cs, Co	[34,35,36]
Jatropha curcas L. (purging nut, physic nut)	Soil	Fe, Al, Cu, Mn, Cr, As, Zn, Hg	[37,38,39]
Lantana camara L. (lantana)	Soil	Pb	[40]
Lens culinaris Medic. (lentil)	Soil	Pb	[41]
Lepidium sativum L. (cress)	Soil	As, Cd, Fe, Pb, Hg	[42,43]
Lactuca sativa L. (lettuce)	Soil	Cu, Fe, Mn, Zn, Ni, Cd, Pb, Co, As	[42,44,45,46]
Medicago sativa L. (alfalfa)	Soil	Cd	[47]
Oryza sativa L. (rice)	Soil	Cu, Cd	[48]
Pistia stratiotes L. (water lettuce)	Water	Cr, Cd, As	[49,50,51]
Pisum sativum L. (pea)	Soil	Pb, Cu, Zn, Fe, Cd, Ni, As, Cr	[31,52,53,54,55]
Rapanus sativus L. (radish)	Soil	As, Cd, Fe, Pb, Cu	[42,56]
Spinacia oleracea L. (spinach)	Soil	Cd, Cu, Fe, Ni, Pb, Zn, Cr	[57,58,59,60,61]
Solanum nigrum L. (black nightshade)	Soil	Cd	[62,63,64]
Sorghum bicolor L. (sorghum)	Soil	Cd, Cu, Zn, Fe	[65]
Zea mays L. (corn)	Soil	Cd, Pb, Zn, Cu	[23,61,66]

3. Conclusions

Phytoremediation is a remediation technology to clean up the contaminants from environment by using green plants. Phytoremediation can be an alternative solution as a green technology to treat heavy metal contaminated areas. According to previous studies, several plants have a high potential as heavy metals bioaccumulator and can be used for phytoremediation process of heavy metals.

References

[1] Briggs D 2003 Environmental pollution and the global burden disease *British Medical Bulletin* **68** 1-24
[2] Jarup L 2003 Hazards of heavy metal contamination *British Medical Bulletin* **68** 167-82
[3] Suvaryan Y, Sargsyan V and Sargsyan A 2011. The problem of heavy metal pollution in The Republic of Armenia: overview and strategies of balancing socioeconomic and ecological development *Environmental Heavy Metal Pollution and Effects on Child Mental*

Developmnet: Risk and Prevention Strategies ed L I Simeonov, M V Kochubovski and B G Simeonova (Springer Science and Business Media) pp 309-15

[4] Adesuyi A A, Hjoku K L and Akinola M O 2015 Assessment of heavy metals pollution in soil and vegetation around selected industries in Lagos State, Nigeria *J. Geosci. Env. Prot.* **3** 11-19

[5] Jiao X, Teng Y, Zhan Y, Wu J and Lin X 2015 Soil heavy metal pollution and risk assassment in Shenyang industrial district, Northeast China *Plos One* **10(5)** 1-9

[6] Henry J R 2000 *An Overview of the Phytoremediation of Lead and Mercury* (Washington : US Environmental Protection Agency)

[7] Cunningham S D. Berti W R and Huang J W 1995 Phytoremediation of contaminated soils *TIBTECH* **13** 393-97

[8] Mulligan C N, Yong R N and Gibbs B F 2001 Remediation technologies for metal-contaminated soils and groundwater: an evaluation *Engineering Geology* **60** 193-207

[9] Hashim M A, Mukhopadhyay S, Sahu J N and Sengupta B 2011 Remediation technologies for heavy metal contaminated groundwater *Journal of Environmental Management* **92** 2355-88

[10] Tangahu B V, Abdullah S R S, Basri H, Idris M, Anuar N and Mukhlisin M 2011 A review on heavy metals (As, Pb, and Hg) uptake by plants through phytoremediation. *International Journal of Chemical Enineering* 939161(2011)31

[11] Susarla S, Medina V F and McCutheon S C 2002 Phytoremediation: an ecological solution to organic chemical contamination *Ecological Engineering* **18** 647-58

[12] Raskin I, Smith R D and Salt D E 1997 Phytoremediation of metals: using plants to remove pollutants from the environment *Current Opinion in Biotechnology* **8** 221-228

[13] Padmavathiamma P K and Li L Y 2007 Phytoremediation technology: hyperaccumulation metals in plants *Water Air Soil Pollut*. **184** 105-26

[14] Vangronsveld J, Herzig R, Weyens N, Boulet J, Andriaensen K, Ruttens A, Thewys T, Vassilev A, Meers E, Nehevajova E, van der Lelie D and Mench M 2009 Phytoremediation of contaminated soils and groundwater: lesson from the fiel. *Environ. Sci. Pollut. Res.* 859(2009)30

[15] Ali H, Khan E and Sajad M A 2013 Phytoremediation of heavy metals – concepts and applications *Chemosphere* **91** 869-81

[16] Dixit R, Wasiulah, Malaviya D, Pandiyan K, Singh U B, Sahu A, Shukla R, Singh B P, Rai J P, Sharma P K, Lade H and Paul D 2015 Bioremediation of heavy metals from soil and aquatic environment: An overview of principles and criteria of fundamental processes *Sustainability* **7** 2189-212

[17] Lasat M M 2000 Phytoextraction of metals from contaminated soil: a review of plant/soil/metal interaction and assessment of pertinent agronomic issues *J. Hazardous Substance Res.* **2** 1-25

[18] Gaur A and Adholeya A 2004 Prosfects of arbusclar mycorrhizal fungi in phytoremediation of heavy metal contaminated soils *Current Science* **86**(4) 528-34

[19] EPA (U.S. Environmental Protection Agency) 2000 *Introduction to Phytoremediation* (Ohio: State Environmental Protection Agency) pp 104

[20] Goland-Goldhirsh A 2006 Plant tolerance to heavy metals, a risk for food toxicity or a means for food fortification with essential metals: the *Allium schoenoprasum* model *Soil and Water Pollution Monitoring, Protection and Remediation* ed I Twardowska, H E Allen and M M Haggblom (Amsterdam: Spinger) pp 479-86

[21] Dasgupta S, Satvat P S and Mahinrakar A B 2011 Ability of *Cicer arientinum* (L.) for bioremoval of lead and chromium from soil *IJTES* **2**(3) 338-41

[22] Rahman M F, Islam M, Begum M C, Kabir A H and Alam M F 2016 Genentic variation in cadmium tolerance is related to transport and antioxidant activities in field peas (*Pisum sativum* L.) *Arch. Agron. Soil Scie.* **63**(4) 578-85
[23] Tiecher T, Ceretta C A, Ferreira P A A, Lourenzi C A, Tiecher T, Girotto E, Nicoloso F T, Soriani H H, De Conti L, Mimmo T, Cesco S and Brunetto G 2016 The potencial of *Zea mays* L. in remediating copper and zinc contaminated soils for grapevine production *Geoderma* **262** 52-61
[24] Belimov AA, Hontzeas N, Safranova V I, Demchinskaya S V, Piluzza G, Bullitta S and Glick B R 2005 Cadmium-tolerant plant growth-promoting bacteria associated with the roots of Indian mustard (*Brassica juncea* L. Czern.) *Soil Biol. Biochem*. **37** 241-50
[25] Takeda R, Sato Y, Yoshimura R, Komemushi S and Sawabe A 2006 Accumulation of heavy metals by cucumber and *Brassica juncea* under different cultivation conditions *Proc. Ann. Int. Conf. on Soil Sediments Water Energy (Massachusetts)* **11** (California: The Barkeley Electronic Press) pp 293-99
[26] Turan M and Esringu A 2007 Phytoremediation based on canola (*Brassica napus* L.) and Indian mustard (*Brassica juncea* L.) planted on spiked soil by aliquot amount of Cd, Cu, Pb, and Zn *Plant Soil Environ.* **53(1)** 7-15
[27] Singh A and Fulekar M H 2012 Phytoremediation of heavy metals by *Brassica juncea* in aquatic and terrestrial environment *The Plant Family Brassicaceae: Contribution Towards Phytoremediation* ed N A Anjum, I Ahmad, M E Pereira, A C Duarte, S Umar and N A Khan (Amsterdam: Springer Science+Business Media) pp 153-69
[28] Sharma H 2016 Phytoremediation of lead using *Brasica juncea* and *Vetiveria zizanoides Int. J. Life Sci. Res.* **4**(1) 91-96
[29] Sheng X F and Xia J J 2006 Improvement of rape (*Brassica napus*) plnat growth and cadmium uptake by cadmium-resistant bacteria *Chemosphere* **64** 1036-42
[30] Dell'Amico E, Cavalva L and Andreoni V 2008 Improvement of *Brassica napus* growth under cadmium stress by cadmium-resistant rhizobacteria *Soil Biol. Biochem*. **40** 74-84
[31] Garg N, Singla P and Bhandari P 2014 Metal uptake, oxidative metabolism, and mycorrhization in pegeon pea and pea under arsenic and cadmium stress *Turk. J. Agric. For.* **39** 234-50
[32] Wani P A, Khan M S and Zaidi A 2007 Impact of heavy metal toxicity on plant growth, symbiosis, seed yield and nitrogen and metal uptake in chickpea *Australian J. Exp. Agric.* **47** 712-20
[33] Kambhampati M S and Vu V T 2013 EDTA enhanced phytoremediation of copper contaminated soils using chickpea (*Cicer aeritinum* L.) *Bull. Environ. Contam. Toxicol.* **91** 310-13
[34] Alvarado S, Guedez M, Lue-Meru M P, Nelson G, Alvaro A, Jesus A C and Gyula Z 2008 Arsenic removal from water by bioremediation with the aquatic plants water hyacinth (*Eichhornia crassipes*) and lesser duckweed (*Lemna minor*) *Biosource Tech.* **99** 8436-40
[35] Mishra V K and Tripathi B D 2009 Accumulation of chromium and zinc from aqueous solutions using water hyacinth (*Eichornia crassipes*) *J. Hazardous Materials* **164** 1059-63
[36] Saleh H M 2012 Water hyacinth for phytoremediation of radioactive waste simulate contaminated with cesium and cobalt radionuclides *Nuclear Engineering and Design* **242** 425-32
[37] Jamil S, Abhilash P C, Singh N and Sharma P N 2009 *Jatropha curcas*: a potential crop for coal fly ash *J. Hazards Materials* **172** 269-75

[38] Yadav S K, Juwarkar A S, Kumar P, Thawale P R, Singh S K and Chakrabarti T 2009 Bioaccumulation and phyto-translocation of arsenic, chromium, and zinc by *Jatropha curcas* L.: impact of diary sludge and biofertilizer *Biosource Tech.* **100** 4616-22
[39] Marrugo-Negrete J, Durango-Hernandez J, Pinedo-Hernandez J, Olivero-Verbel J and Diez S 2015 Phytoremediation of mercury-contaminated soils by *Jatropha curcas Chemosphere* **127** 58-63
[40] Alaribe F O and Agamuthu P 2015 Assessment of phytoremediation potencials of *Lantana camara* in Pb impacted soil with organic wasted additives *Ecological Engineering* **83** 513-20
[41] Wani P A and Khan M S 2012 Bioremediation of lead by a plant growth promoting *Rhizobium* species RL9 *Bacteriology J.* **2**(4) 66-78
[42] Gunduz S, Uygur F N and Kahramanoglu I 2012 Heavy metal phytoremediation potencials of *Lepidium* sativum L., *Lactuca sativa* L., *Spinacia oleracea* L. and *Raphanus sativus* L. *Herald J. Agric. Food Sci. Res*. **1**(1) 1-5
[43] Smolinska B and Szczodrowska A 2016 Antioxidative response of *Lepidium sativum* L. during assisted phytoremediation of Hg contaminated soil *New Biotechnology* NBT896(2016)10
[44] Achakzai A K K, Bazai Z A and Kayani S A 2011 Accumulation of heavy metals by lettuce (*Lactuca sativa* L.) irrigated with different levels of wastewater of Quetta City *Pak. J. Bot.* **43**(6) 2953-60
[45] Rashid A, Mahmood T, Mehmood F, Khalid A, Saba B, Batool A and Riaz A 2014 Phytoaccumulation, competitive adsorption and evaluation of chelators-metal interaction in letuce plant *Environ. Eng. Management J.* **13**(10) 2683-92
[46] Quainoo A K, Konadu A and Kumi M 2015 The potential of shea nut shells in phytoremediation of heavy metals in contaminated soil using lettuce (*Lactuca sativa*) as a test crop *J. Bioremed. Biodeg.* **6**(1) 1-7
[47] Ghnaya T, Mnassri M, Ghabriche R, Wali M, Poschenriender C, Lutts S and Abdelly C 2015 Nodulation by *Sinorhizobium meliloti* originated from a mining soil alleviates Cd toxicity and increases Cd-phytoextraction in *Medicago sativa* L. *Frontiers in Plant Science* **6** 1-10
[48] Li P, Wang X, Zhang T, Zhou D and He Y 2008 Effect of several amendments on rice growth and uptake of copper and cadmium from a contaminated soil *J. Environ. Sci.* **20** 449-55
[49] Akter S, Afrin R, Mia M Y and Hossen M Z 2014 Phytoremediation of chromium (Cr) from tannery effluent by using water lettuce (*Pistia stratiotes*) *ASA University Review* **8**(2) 149-56
[50] Das S, Goswami S and Talukdar A D 2014 A study on cadmium phytoremediation potential of water lettuce, *Pistia statiotes* L. *Bull. Environ. Contam*. Toxicol. **92** 169-74
[51] Farnese F S, Oliveira J A, Lima F S, Leao G A, Gusman G S and Silva L C 2014 Evaluation of the potential of *Pistia stratiotes* L. (water lettuce) for bioindication and phytoremediation of aquatic environments contaminated with arsenic *Braz. J. Biol.* **74**(3) 103-12
[52] Malecka A, Piechalak A and Morkunas I 2008 Accumulation of lead in root cells of *Pisum sativum Acta Physiol Plant* **30** 629-37
[53] Wani P A, Khan M S and Zaidi A 2008 Effects of heavy metal toxicity on growth, symbiosis, seed yield and metal uptake in pea grown in metl amanded soil *Bull. Environ. Contam. Toxicol*. **81** 152-58
[54] Hegedusova A, Jakabova S, Vargova A, Hegeus O and Pernyeszi T J 2009 Use of phytoremediation techniques for elimination of lead from polluted soils *Nova Biotechnologica* **9**(2) 125-32
[55] Sharma S, Sharma P and Mehrotra P 2010 Bioaccumulation of heavy metals in *Pisum sativum* L. gowing in fly ash amandd soil *J. American Sci.* **6(6)** 43-50

[56] Hatano K, Kanazawa K, Tomura K, Yamatsu T, Tsunoda K and Kubota K 2016 Molases melanoidin promotes copper uptake for radish sprouts: the potential for an accelerator of phytoextraction *Environ. Sci. Pollut. Res.* **23** 17656-63
[57] Patel M and Subramanian R B 2006 Effect of a chelating agent on lead uptake by *Spinacia olearea Poll. Res.* **25**(1) 77-79
[58] Salaskar D, Shrivastava M and Kale S P 2011 Bioremediation potential od spinach (*Spinacia oleracea* L.) for decontamination of cadmium in soil *Current Sci.* **101**(10) 1359-63
[59] Pathak C, Chopra A K and Zivastava S 2013 Accumulation of heavy metals in *Spinacia oleracea* irrigated with paper mill effluent and sewage *Environ. Monit. Assess.* **185** 7343-52
[60] Jahanbakhshi S, Rezaei M R and Sayyari-Zahan M H 2014 Optimization of phytoremediation in Cd-contaminated soil by using Taguchi method in *Spinacia oleracea Proceedings of the International Academy of Ecology and Environmental Sciences* vol 4 ed W Zhang (Hongkong: International Academy of Ecology and Evironmental Sciences) pp 185-93
[61] Abhilash M R, Srikantaswamy S, Shiva Kumar D, Jagadish K and Shruthi L 2016 Phytoremediation of heavy metal industrial contaminated soil by *Spinacia oleracea* L. and *Zea mays* L. *Int. J. Applied Sci.* **4**(1) 192-99
[62] Wei S, Zhou Q and Koval P V 2006 Flowering stage characteristic of cadmium hyperaccumulator *Solanum nigrum* L. and their significance to phytoremediation *Sci. Total Environ.* **369** 441-46
[63] Wei S, Li Y, Zhou Q, Srivastava M, Chiu S, Zhan J, Wu Z and Sun T 2010 Effect of fertilizer amandments on phytoremediation of Cd-contaminated soil by newly discovered hyperaccumulator *Solanum nigrum* L. *J. Hazardous Materials* **176** 269-73
[64] Ji P, Sun T, Song Y, Ackland M L and Liu Y 2011 Strategies for enhanching the phytoremediation of cadmium-contaminated agricultural soils by *Solanum nigrum* L. *Environ. Poll.* **159** 762-68
[65] Pinto A P, Mota A M, de Varennes A and Pinto F C 2004 Influence of organic matter on uptake of cadmium, zinc, copper and iron by shorgum plant *Science of the Total Environ.* **326** 239-47
[66] Mojiri A 2011 The potencial of corn (*Zea mays*) for phytoremediation of soil contaminated with cadmium and lead *J. Biol. Environ. Sci.* **5**(13) 17-22