International Journal of Research in Advent Technology, Vol.6, No.5, May 2018
E-ISSN: 2321-9637
Available online at www.ijrat.org

Bioremediation of Arsenic contaminated soil and its impacts on Plants and Human Health

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Abstract- The soil is the medium which supports the plants and acts as the reservoir for nutrients and water which is being deteriorated due to increasing anthropogenic activities which render the soil becoming useless for plant growth. Use of pesticides, combustion of fossil fuels, power plants emissions and natural processes like volcanic eruptions and weathering plays the lead role resulting in contamination of soil with toxic and heavy metals like Arsenic, which is not only toxic but also acquires carcinogenic properties that enters the human food chain through food sources which are grown in the soil contaminated due to such substance. Hence it can result in severe health issues mainly skin lesion, cancer of skin, lungs, kidney, liver and accumulation of As at high concentration can also lead to the death of the individual. Phytoremediation is the solar driven, environmental friendly method which uses plants called Hyperaccumulator which easily accumulate the contaminant from the soil and stores it with different tissues of the plants and making soil reusable. Plants having greater tendency to accumulate high concentration of As are usually used to make the soil portable without disturbing the soil quality. The review is based on the use of different plants which are mostly used to remediation of soil and new plants are also being introduced so that better results can be obtained and make the soil useful for better growth and development.

Keywords: Soil, Arsenic, Toxicity, Phytoremediation, Hyper – Accumulator.

1. INTRODUCTION

Arsenic In Nature:

Arsenic is an element which is found in its natural form and also due to the increasing human activities which was first discovered by Albert Magnus, a German Alchemist in 1250 AD. It is a chemical element having atomic number 33 and symbol As, which is a natural component of the Earth's crust but is present in a very minute amount in soil, air and water. The concentration of Arsenic is rapidly increasing in the world due to natural as well as human activities. Arsenic is a metalloid and it is extremely difficult to handle as it is highly toxic due to its ubiquitous distribution. As is released by natural activities such as weathering of rocks, volcanic eruptions and number of human activities. As is usually found in many chemical forms in combination with other elements and are furthered classified as an organic form containing carbon and inorganic forms which do not have any carbon contains. As is mainly present in four oxidation forms: -3, 0, +3 and +5. As acts is a metalloid and exhibit the properties of a metal as well as non-metal. Inorganic arsenic (Arsenite +3) is more toxic as compared to that of organic arsenic (Arsenate +5) as it is more soluble.[35] Elevated levels of Arsenic in soil have resulted due to natural disasters and growing needs of human beings which led to anthropogenic activities like smelting of ores, mining, burning of coal, application of pesticides containing derivatives of arsenic and industrial activities.[15]

In recent years there is a major increase in the level of arsenic in soil in many countries which was raised the concern for developing new and environmental friendly techniques to resolve such problems as arsenic is highly soluble and have toxic effects. It has being a global environmental as well as

a health issue because of its toxic and carcinogenic nature.[29],[36] In soil As concentration ranged between 5 – 10 mg / kg and if it ranges above 20 mg / kg then it is considered to be high and a danger to the environment.[32] Arsenic also gets attached to very minute particles available in air and stays within air for a very long time. Arsenic is not biodegradable, it gets converted from organic to inorganic form or inorganic to organic form and gets easily reacted with other chemicals or can travel between air, water and soil. Anthropogenic sources like emissions from the power plants and combustion of fossil fuels also release the airborne arsenic which are extremely minute particles that stay in the air for many days and can easily travel long distances. The windborne dust containing arsenic which is found in larger particles can get easily deposited on the ground and further result in contamination of soil. Arsenic and its derivatives are largely used in the production of pesticides, herbicides, wood preservatives, as it tends to be toxic to insects, pests and bacteria.[41] In past, the use of chromated copper arsenate also called as CCA or Tenalith which was a highly extensive method was used in the process of wood treatment but due to its toxicity of arsenic, its use was banned in consumer products in 2004, which was proposed by European Union and the United States.[29],[26]

In nature, arsenic and its compounds are mobile and cannot be destroyed and can interact with the oxygen and many molecules which are present in air, water and soil. Many of the arsenic compounds are soluble in water which can easily get dissolved within the water bodies and hence result in contamination of lakes, rivers, ponds and also the groundwater which have resulted in a severe threat to public health and has raised an alarming concern for such detrimental effects of the toxic element. Compared to that of air, As have also been a major source of soil contamination which has been reported in many parts of the world. The plants grown in such soil can have an elevated level of As which can directly or indirectly enter within the food chain and clear evidence of As poisoning have also been reported in many places where a high level of As was present in the soil. A large group of the population have also been affected by the adverse effect of arsenic in different regions.[49],[13] Several factors are also influencing the solubility and identification of As, mainly the pH and the redox reaction. When the pH increases the solubility of arsenate is increased and arsenite is decreased and vice a versa when pH is decreased.[43]

2. EXPOSURE OF ARSENIC IN PLANTS AND ITS EFFECTS

Generally, plants take up arsenic from the soil through the roots and the plants grown under water termed as the submerged plants can take up arsenic from the leaves and the water column.[60] The accumulation and transportation of As differ from plant types, species and their habitat. It has been observed in many plants that As is primarily found in roots rather than that of the shoots. A 15 times higher concentration of As was found in *Spartina Pectinata* [46] and about 28 - 70 times higher concentration of As in rice was found in the roots as compared to that of the shoots.[3] Some other plant species like radish have a high concentration of As in shoots as compared to that of the roots.[50] The As is thus transported to different parts of plants through Apoplast and further to plant cytoplasm through which it is further carried to other parts of plants. The plants which are exposed to As produces Reactive Oxygen Species (ROS) which causes damage to the DNA, proteins and lipids [48] and it is also highly toxic to the plants as it is transported and can disturb the central cellular functions.[51] As easily gets accumulated in the plants and can be transported to other parts of plants which are usually used as the source of food, and easily enters the food chain depending on the oxidation state which is mainly due to its solubility, mobility and phytotoxicity of As.[30]

A large group of scientists have been concentrating on the plant species and its effects and the risk of exposure to the human beings. Different plants have different capacity to accumulate As which depends on the soil types and the species of plant

grown in the soil. Example, As accumulation in the fronds of *Pteris vittata,* is greater than 22,000 mg / kg. [27] As is a non – essential element which have toxic effects on plants where roots are the first parts which become exposed to As and its translocation to shoots which severely inhibits the plant growth and suspension of reproductive capacity of the pants by loss of fertility and fruit production [19] and further results in interference in metabolic activities of plants which leads to plant death. The cellular membrane of the plants also becomes damaged due to exposure of As which leads to the conclusion of oxidative stress in As toxicity.[48] The rate of transpiration can be reduced due to elevated levels of As.[52] It was reported that low As causes repression of nitrogen-fixing root nodules in soybean.[57] It is also been reported that the at low As concentration the plant growth is stimulated and reduction in plant biomass.[52],[61],[9],[10],[33] This is mainly due to direct interaction of As with plant metabolism or by interaction with plant nutrients. Thus the elevated level of As in soil tends to act as the toxic element for the plant due to which the plants show depressed growth and development of plants becomes suspended. It is also observed that at high concentration As causes many chemical and physiological dysfunctions including uptake of water and nutrients, disruption of enzyme and chloroplast structure, reduced capacity of photosynthesis, necrosis and ultimately death.[17],[16],[8],[25]

3. EXPOSURE OF ARSENIC TO HUMANS AND ITS EFFECTS

Arsenic belongs to the group 15 elements and is extremely poisonous belonging to class – 1 human carcinogenic substance. Arsenic exposure usually occur by inhalation and dermal layer of the human body which refers as the minor route of exposure in any population whereas the major routes is oral exposure via drinking water which is contaminated through As or by the food crops which are grown in the soil which is contaminated by As. As is naturally present in the Earth's crust but most of the soil and water contamination are the result of anthropogenic activities. Such contamination also results due to atmospheric deposition, soil erosion of metal ions and leaching of heavy metals which mainly includes As, metal corrosion and evaporation from water resource.[37]

As is the element which is having the long history of poison due to its occurrence, toxic effects and potential health hazards to human population. Ingestion of a very low dose of As through food or water to humans in the most important pathway where absorption in stomach and intestine takes place which is furthered released in the bloodstream. As is converted to less toxic substance by the liver and is mainly excreted via urine. Only if the human body is exposed to very high exposure, it leads to accumulation within the body. Chronic exposure of As causes relevance of cutaneous lesions [12],[59] which includes melanosis also known as hyperpigmentation which is termed as a condition of excessive production of melanin in the skin or other tissues, keratosis which refers as a horny growth especially on the skin and leukomelanosis also known as hypopigmentation. Arsenic is a very well known carcinogen which causes skin cancer, lung cancer, bladder cancer, kidney cancer and liver cancer.[23],[40] If As is ingested it can be resulted in symptoms like gastrointestinal irritation but if it is inhaled than rapid biotransformation takes place in liver [56] and symptoms reflecting the diversity of organ damages may result.[5]

In acute toxicity the effects are usually seen in short time span in which a person notices metallic taste, garlic odour in breath with some sort of swallowing difficulties, symptoms like muscular pain, weakness, severe nausea, vomiting and diarrhoea. Symptoms like numbness in hands and feet, rashes on body and intense thirst is also observed, whereas in severe poisoning the skin usually becomes cold [6] and kidney damage resulting in decreased urine output frequently takes place. Excess toxicity further results in coma, seizures and death of the person. Thus there come alarming need for techniques which can be used for removing As from nature due to increasing

incidences of As poisoning are being observed throughout the world.

4. BIOREMEDIATION METHOD

There are many techniques in the world which can be used for treating the soil which is contaminated by heavy metals including physical techniques line landfilling, soil excavation, deep burial and capping, while chemical methods such as the use of strong acids and chelators to wash the contaminated soil. The use of such method is very less as it is very expensive and also because the soil which is contaminated is huge in volume, on the other hand, these methods also affect the soil properties and destroy the biodiversity of the particular areas and make the soil unfit and useless for plant growth.[38] Therefore there arises the need to move to a technique which is not only cost-effective but also environmental friendly. Bioremediation method is one of the best options which is a natural medium to get rid of such problem and make to soil free from contamination that can be suitable for plant growth and development. Bioremediation is a process which is basically used to treat the contaminated water and contaminated soil by changing the physical and biological environmental conditions to stimulate the growth of microorganisms and degrade the pollutants. It is a cheap method which does not have any negative impact on the soil and biodiversity of the nearby area. There are a number of bioremediation techniques which involves land farming, composting, phytoremediation, mycoremediation, bioventing, bioleaching and biostimulation.

Phytoremediation:

Phytoremediation is a low-cost technique which uses the ability of the plant to concentrate the element from the soil and metabolize in their tissues. The schematic representation of Phytoremediation approaches is described in figure 1. It is referred to the ability and capacity of the plants to accumulate, degrade and make the soil harmless for plant growth. Such plants used in this technique are termed as Hyperaccumulator. Toxic metals, as well as heavy metals, are the main target which can be removed from the environment by using such plants. This is a diverse collection of plant-based technology to clean contaminated environmental resources.[11] These plants have gained interest for scientific and also to understand the mechanism of hyperaccumulation of heavy metals.[42],[47] But the most important thing is that hyperaccumulator plants are specific for particular metal [4] and are depending on the climatic conditions. Various plants have the tendency to accumulate high concentration of As within their tissues which plays a very important role in the process of Phytoremediation but have some limitations.

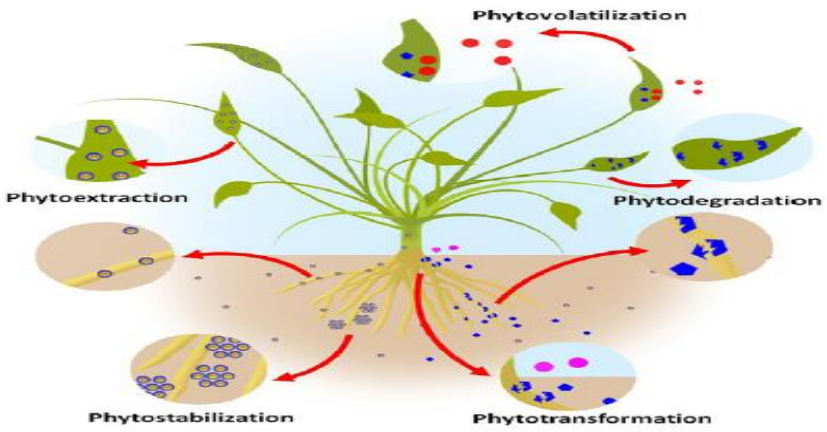

Fig 1 : Schematic representation of Phytoremediation Approaches [39]

The *Pteris vittata* [27],[7] is one of the best options which is used as a hyperaccumulating plant which has the tendency to store high concentration of As in their shoots but needs proper availability of water for its growth. As toxicity in plants can generate Reactive Oxygen Species (ROS) [31] which can cause damage to biomolecules and even cell death [21] hence the plants used in such cases should have evolved mechanism to protect the cell from the effects of ROS by synthesizing enzymatic and non – enzymatic antioxidants. The usefulness and its effectiveness depend on the ability of the plant to remove As and make it available for the plant uptake.[22],[2] It has been seen that rather than the crop plants, As hyperaccumulator is capable to access the unavailable AS in soil through root exudates. [55],[20] Other than *P. vittata* there are many other plants which also plays a key role in the technique for removing As from soil as well as water namely like *Lepidium sativum* (watercress) [45] and *Eichhornia crassipes* (water hyacinth).[1]

The process of phytoremediation is further categorized into phytoextraction, phytostabilization. Phytovolatilization and rhizofiltration which are also extensively used for uptake of toxic heavy metal like As by the means of plants.[14] Usually, it is seen that the plants tolerant to metal and metalloids are a basic requirement for phytoremediation.[54] Plants like *Populus* species are also being used as perennial plants which have the tendency to tolerate high metal propagation and soil stabilization potential.[58] *Chorella vulgaris* a single cell phytoplankton which is having the tendency to tolerate heavy metals is also one of the better options for As remediation [34],[44],[53] which have shown great results in some regions during field trials in Thailand.[24] Other ferns like *Pteris genus*, *P. longifolia*, *P. cretica*, *P. umbrosa* [28],[62] as well as *Pityrogramma calomelanos* [18] are also some of the plants which are recently determined to hyper-accumulate As. There are a number of plants which can be used for such hyperaccumulation which plays a very vital role in the removal of As from the soil and making it reusable and free from contamination.

5. CONCLUSION

Natural calamities, industrialization and anthropogenic sources lead the environment especially the soil and water to get contaminated by heavy metal which in future tends to become more and more toxic. It not only affects the plant growth but also render the growth and development of the plant and leading it to the eventual death of plants, which if not taken care of can lead to a barren land fit for nothing. Further, it also enters the human food chain and leads to skin lesions, cancer of bladder, lung, kidney, liver and long-term exposure results in the death of the individuals. It can also contaminate the groundwater and result in a disturbance in the aquatic ecosystem. Hence it is it becomes very essential to get serious attention towards the increasing issues and move to an environmental friendly approach which is conventional as well as cost-effective. Phytoremediation is one of the best methods which is extensively used throughout the world and getting the solution to the improvement of soil quality and making the land free from toxic heavy metals. Although the method takes longer time for removing the contaminants from the soil, it is very simple to implement. The use of appropriate plant species that have the ability to accumulate the maximum amount of contaminants is the best use of plants and also allows generation of biomass by controlling carbon emission. Good knowledge and proper selection of plants can give good results making the soil fit for plants to grow and removing the maximum proportion of toxic and heavy metal from the soil.

REFERENCES

1. Al Rmalli SW, Harrington CF, Ayub M, Haris PI. 2005. A biomaterial based approach for arsenic removal from water. J Environ Monit. 7:279–282.
2. Anawar HM, Garcia-Sanchez A, Santa Regina I. 2008. Evaluation of various chemical extraction methods to estimate plant-available arsenic in mine soils. Chemosphere. 70:1459–1467.
3. Azizur Rahman, M., Hasegawa, H., Mahfuzur Rahman, M., Nazrul Islam, M., Majid Miah, M.A. & Tasmen, A., (2007). Accumulation of arsenic in tissues of rice plant (*Oryza Sativa* L.) and its distributions in fractions of rice grains. Chemosphere Vol. 69, pp. 942-948.
4. Baker, A.J.M. and Brooks, R.R. 1989. Terrestrial higher plants which hyperaccumulate metallic elements—A review of their distribution, ecology and phytochemistry. *Biorecovery* **1**, 81–126.
5. Bansal, S. K., Haldar, N., Dhand, U. K. et al. Phrenic neuropathy on arsenic poisoning. *Int. J. Dermatol*. 30, pp 304-306, 1991.
6. Barrett, J. C., Lamb, P. W., Wang, T. C., and Lee, T. C. Mechanisms of arsenic induced cell transformation. *Biol. Trace Elem. Res*. 21, pp 421-429, 1989.

7. Caille, N., Swanwick, S., Zhao, F.J., and McGrath, S.P. 2004. Arsenic hyperaccumulation by *Pteris vittata* from arsenic contaminated soils and the effect of liming and phosphate fertilisation.*Environ. Pollut.* **132**, 113–120.
8. Campos NV, Loureiro ME, Azevedo AA. 2014. Differences in phosphorus translocation contributes to differential arsenic tolerance between plants of *Borreria verticillata* (Rubiaceae) from mine and non-mine sites. Environ Sci Pollut Res 24:5586–5896.
9. Carbonell-Barrachina, A. A., Burló, F., Burgos-Hernández, A., López, E., and Mataix J. (1997). The influence of arsenite concentration on arsenic accumulation in tomato and bean plants. Sci. Hortic. 71, 167–176.
10. Carbonell-Barrachina, A. A., Burló, F., and Mataix, J. (1998b). Response of bean micronutrient nutrition to arsenic and salinity. J. Plant Nutr. 21, 1287–1299.
11. Cunningham SD, Shann JR, Crowley DE, Anderson TA. 1997. Phytoremediation of contaminated water and soil. In: Kruger EL, Anderson TA, Coats JR, editors. Phytoremediation of soil and water contaminants. ACS symposium series 664. Washington (DC): American Chemical Society. p. 2–19.
12. Das NK, Sengupta SR. Arsenicosis: diagnosis and treatment. Indian J Dermatol Venereol Leprol. 2008;74(6):571–81.
13. Edwards M, Johnson L, Mauer C, Barber R, Hall J (2014) Regional specific groundwater arsenic levels and neuropsychological functioning: a crosssectional study. Int J Environ Health Res 24: 546-557.
14. Erakhrumen A, Agbontalor A. 2007. Review Phytoremediation: an environmentally sound technology for pollution prevention, control and remediation in developing countries. Educational Res Review 27:151–156.
15. Fergusson, J. E. (1990) *The Heavy Elements: Chemistry, Environmental Impacts and Health Effects*. Pergamon Press, Oxford, UK, p. 614
16. Finnegan P, Chen W. 2012. Arsenic toxicity: the effects on plant metabolism. Front Physiol 3:182.
17. Flora SJS. 2011. Arsenic-induced oxidative stress and its reversibility. Free Radic Biol Med 51:257–281.
18. Francesconi, K., Visoottiviseth, P., Sridakchan, W., and Goessler, W. 2002. Arsenic species in an arsenic hyperaccumulating fern, Pityrogramma calomelanos: A potential phytoremediator of arsenic-contaminated soils. *Sci. Total Environ.* **284**, 27–35.
19. Garg, N., and Singla, P. (2011). Arsenic toxicity in crop plants: physiological effects and tolerance mechanisms. Environ. Chem. Lett. 9, 303–321.
20. GonzagaMIS, Santos JAG,Ma LQ. 2008. Phytoextraction by arsenic hyperaccumulator *Pteris vittata* L.from six arsenic-contaminated soils: Repeated harvests and arsenic redistribution. Environ Pollut. 154:212–218.
21. Gunes A, Inal A, Bagci EG, Pilbeam DJ. 2007. Silicon-mediated changes of some physiological and enzymatic parameters symptomatic for oxidative stress in spinach and tomato grown in sodic-B toxic soil. Plant Soil 290:103–114.
22. Gupta AK, Sinha S. 2007. Phytoextraction capacity of the plants growing on tannery sludge dumping sites. Bioresource Technol. 98:1788–1794.
23. IARC (InternationalAgency for Research on Cancer). A review of human carcinogens: arsenic, metals, fibres, and dusts. Lyon: World Health Organization Press; 2012.
24. Jones H, Visoottiviseth P, Bux MK, F¨old´enyi R, Kov´ats N, Borb´ely G, Galb´acs Z. 2009. Case reports: Arsenic pollution in Thailand, Bangladesh and Hungary. In: Garelick H, Jones H, eds. Reviews of environmental contamination and toxicology. Arsenic pollution and remediation: An international perspective. vol 197. New York: Springer. p. 163–187
25. Khalid S, Shahid M, Niazi NK, Rafiq M, Bakhat HF, Imran M, Abbas T, Bibi I, Dumat C. Arsenic behaviour in soil-plant system: Biogeochemical reactions and chemical speciation influences. In "Anjum et al. (Ed.) Enhancing Cleanup of Environmental Pollutants" Non Biological Approaches; Springer Berlin Heidelberg, 2016.
26. *Lichtfouse, Eric (2004). "Electrodialytical Removal of Cu, Cr and As from Threaded Wood". In Lichtfouse, Eric; Schwarzbauer, Jan; Robert, Didier. Environmental Chemistry: Green Chemistry and Pollutants in Ecosystems. Berlin: Springer. ISBN 978-3-540-22860-8.*
27. Ma, L. Q., Komart, K. M., Tu, C., Zhang, W., Cai, Y., & Kennelly, E. D. (2001). A fern that hyperaccumulates arsenic. Nature, 409, 579–579.
28. Ma, L.Q., Komar, K.M., and Kennelley, E.D. 2001b., Methods for removing pollutants from contaminated soil materials with a fern plant. US patent 6302942.
29. Mandal BK, Suzuki KT. 2002. Arsenic round the world: a review. Talanta 58 (1):201-235.
30. Masscheleyn, P. H.; DeLaune, R: D.; Patrick, W. H., Jr. A hydride generation atomic absorption technique for arsenic speciation. *J. Environ. Qual*. **1991**, *20*, 96-100.
31. Meharg AA, Hartley-Whitaker J. 2002. Arsenic uptake and metabolism in arsenic-resistant and nonresistant plant species. New Phytol 154:29–43.

32. Mehmood A, Hayat R, Wasim M, Akhtar M S. 2009. Mechanisms of arsenic adsorption in calcareous soils. J Agric Biol Sci 1:59-65.
33. Miteva, E. (2002). Accumulation and effect of arsenic on tomatoes. Commun. Soil Sci. Plant Anal. 33, 1917–1926.
34. Nacorda JO, Martinez-Goss MR, Torreta NK, Merca FE. 2007. Metal resistance and removal by two strains of the green alga, *Chlorella vulgaris* Beijerinck, isolated from Laguna de Bay Philippines. J Appl Phycol. 19: 701–710.
35. Ng, J.C. 2005. Environmental contamination of arsenic and its toxicological impact on humans. Environ. Chem. 2: 146–160.
36. Niazi NK, Singh B, Shah P. 2011. Arsenic speciation and phytoavailability in contaminated soils using a sequential extraction procedure and XANES spectroscopy. Environ Sci Technol 45:7135–7142.
37. Nriagu JO (1989) A global assessment of natural sources of atmospheric trace metals. Nature 338:47–49
38. Padmavathiamma PK, Li LY. 2007. Phytoremediation technology: Hyper-accumulation metals in plants. Water Air Soil Pollut 184:105–126.
39. Parmar S, Singh V. Phytoremediation Approaches for Heavy Metal Pollution: A Review. J Plant Sci Res. 2015;2(2): 139.
40. Program NT. Report on carcinogens. 12th ed. Research Triangle Park: NTP; 2011.
41. Rahman, F. A.; Allan, D. L.; Rosen, C. J.; Sadowsky, M. J. (2004). "Arsenic availability from chromated copper arsenate (CCA)-treated wood". Journal of Environmental Quality. 33(1): 17380. doi:10.2134/jeq2004.0173. PMID 149643 72.
42. Raskin, I., Smith, R.D., and Salt, D.E. 1997. Phytoremediation of metals using plants to remove pollutants from the environment. *Curr. Opin. Biotech.* **8**, 221–226.
43. Raven, K. P., Jain, A. & Loeppert, R., H. (1998). Arsenite and arsenate adsorption on ferrihydrite: kinetics, equilibrium, and adsorption envelopes. Environmental Science and Technology, Vol. 32, pp. 344-349.
44. RehmanA, ShakooriAR. 2001. Heavy metal resistance *Chlorella* spp., isolated from tannery effluents, and their role in remediation of hexavalent chromium in industrial waste water. Bull Environ Contam Toxicol. 66: 542–547.
45. Robinson B, Duwig C, Bolan N, Kannathasan M, Saravanan A. 2003. Uptake of arsenic by New Zealand watercress (*Lepidium sativum*). The Science of the Total Env. 301:67–73.
46. Rofkar, R., J. & Dwyer, D., F. (2011). Effects of light regime, temperature, and plant age on uptake of arsenic by *Spartina pectinata* and *Carex stricta*. International Journal of Phytoremediation, Vol. 13, pp. 528-537.
47. Salt, D.E., Blaylock, M., Kumar, N.P.B.A., Dushenkov, V., Ensley, B. D., Chet, I., and Raskin, I.1995. Phytoremediation: A novel strategy for removal of toxic metals from the environment using plants. *Biotechnology* **13**, 468–474.
48. Singh, N., Ma, L., Q., Srivastava, M. & Rathinasabapathi, B. (2006). Metabolic adaptations to arsenic-induced oxidative stress in *Pteris vittata* L and *Pteris ensiformis* L. Plant Science, Vol. 170, pp. 274-282.
49. Smedley P, Kinniburgh D (2002) A review of the source, behaviour and distribution of arsenic in natural waters. Appl Geochem 17: 517-568.
50. Smith, P., G., Koch, I. & Reimer, K., J. (2008). Uptake, transport and transformation of arsenate in radishes (*Raphanus sativus*). Science of the total environment, Vol. 390, pp. 188-197.
51. Srivastava, S., Mishra, S., Tripathi, R., D., Dwivedi, S., Trivedi, P., K. & Tandon, P., K. (2007). Phytochelatins and antioxidant systems respond differentially during arsenite and arsenate stress in Hydrilla verticillata (L.f.) Royle. Environmental Science & Technology, Vol. 41, No. 8, pp. 2930-2936.
52. Stoeva, N., and Bineva, T. (2003). Oxidative changes and photosynthesis in Oat plants grown in Ascontaminated soil. Bulg. J. Plant. Physiol. 29, 87–95.
53. Suhendrayatna Ohki A, Kuroiwa T, Maeda S. 1999. Arsenic compounds in the freshwater green microalga *Chlorella vulgaris* after exposure to arsenite. Appl Organomet Chem. 13: 127–133.
54. Tong YP, Kneer R, Zhu YG. 2004. Vacuolar compartmentalization: a second generation approach to engineering plants for phytoremediation. J Trends Plant Sci 9:7–9.
55. Tu SX,Ma L, Luongo T. 2004. Root exudates and arsenic accumulation in arsenic hyperaccumulating *Pteris vittata* and non hyperaccumulating *Nephrolepis exaltata*. Plant Soil. 258:9–19.
56. Vater, M. Methylation of arsenic. In B. A. Fowler(Ed.), Biological and environmental effects of arsenic. *Elsevier*, New York, pp 171-198, 1988.
57. Vázquez, S., Esteban, E., and Carpena, R. O. (2008). Evolution of arsenate toxicity in nodulated white lupine in a long-term culture. J. Agric. Food Chem. 56, 8580–8587.
58. Wan X, Zhang F, Xia X, Yin W. 2008. Effects of cadmium on photosynthesis and chlorophyll fluorescence parameters of solution-cultured poplar plants. J Scientia Silvae Sinicae 44:73–78.

59. WHO. Guidelines for drinking-water quality, addendum to volume 1: recommendations. Geneva; 1998.
60. Wolterbeek, H., Th., van der Meer, A., J., G., M. (2002). Transport rate of arsenic, cadmium, copper and zinc in *Potamogeton pectinatus* L.: radiotracer experiments with 76As, 109,115Cd, 64Cu and 65,69mZn. The Science of the Total Environment, Vol. 287, pp. 13-30.
61. Woolson, E. A.,Axley, J. H., and Kearney P. C. (1971). The chemistry and phytotoxicity of arsenic in soils. I. Contaminated field soils. Soil Sci. Soc. Am. Proc. 35, 938–943.
62. Zhao, F.J., Dunham, S.J., and McGrath, S.P. 2002. Arsenic hyperaccumulation by different fern species. *New Phytol.* **156**, 27–31.