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CADMIUM BIOREMEDIATION: A REVIEW

Sneh Lata [1], Hemant Preet Kaur [1] and Tulika Mishra [* 2]

University Institute of Biotechnology [1], Chandigarh University, Gharuan - 140413, Punjab, India.
Xavier University [2], School of Medicine, Aruba.

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Correspondence to Author:
Dr. Tulika Mishra

Assistant Professor,
Xavier University, School of Medicine, Oranjestad, Aruba.

E-mail: tulikares@gmail.com

ABSTRACT: The Increase in industrialization has raised the levels of heavy metal pollution in the country. Heavy metals are entering through the water supply, which is ultimately reaching into streams, lakes, rivers, and groundwater. So, ultimately, these heavy metals are causing environmental pollution, which is becoming a threat to humans as well as animals as the heavy metal pollution is linked with various life-threatening diseases as discussed below. It is very difficult to remove these potent and hazardous metals from the environment as they cannot be degraded chemically and biologically. Bioremediation offers an economical approach to remove these contaminants. Bioremediation uses both live microorganisms as well as plants (Phytoremediation) for the removal of heavy metals. Among toxic heavy metals, cadmium is one such metal which is harmful to flora and fauna. The study shows the present concrete scenario as well as the previous findings in this field of remediation of potent heavy metals, especially cadmium, which is very hazardous.

INTRODUCTION: Heavy metals are naturally present on earth: Lenntech, 2004 defined heavy metals as an element with high density. Mercury, cadmium, arsenic, chromium, and lead, etc. are few examples of heavy metals which are extremely toxic. Some metals are required for the metabolism of humans like copper *etc*. but at higher concentrations, they act as a toxin. Heavy metals are highly toxic because they start accumulating, and their breakdown is either slow, or they do not degenerate, resulting in many health problems. Increase in industrialization has raised the levels of heavy metal pollution in the country.

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Heavy metals are entering into water supplies through waste material, which is releasing them into streams, lakes, and rivers. So ultimately these heavy metals are causing environmental pollution. It is very difficult to remove these potent and hazardous metals from the environment as they cannot be degraded chemically and biologically. The main metals which are hazardous are cadmium, lead, mercury, Zinc, Chromium, and copper. These heavy metals are extremely toxic and can mainly contaminate soil water *etc*. [1, 2] The aquatic biota can be badly affected by the presence of heavy metals [3]. Nowadays their presence is also visible in the food chain, which is very harmful for mankind.

There are many industries that are releasing heavy metals in their effluent. Among all these potent metals the cadmium is one such non-essential heavy metal having high toxicity at even low dosage to all organisms.

Cadmium can cause reproductive system failure, brain damage, kidney damage to human beings [4,] and also it is related to cancer [5]. Renal damage was also reported due to cadmium toxicity [6]. Cadmium can enter into aquatic life through sewage sludge. Discharges which contain cadmium should strictly control as they are highly toxic and tends to accumulate in tissues of organisms [7]. There is a lesser number of reports showing bioremediation of cadmium by microorganisms. Environmental pollution due to cadmium particulate from industries is increasing day by day. It is entering the food chain and ultimately reaching the environment. The purpose of the study is to completely remove the cadmium by using natural process, *i.e.* with the help of naturally occurring micro-organisms having potential to remove it completely from the environment.

Cadmium and its Utility: Cadmium is a silver-white colored metal and has a solubility in acids. Friedrich Strohmeyer, a German chemist, discovered cadmium in 1817. Cadmium has one interesting feature in it that it is noncorrosive, and that's why it is used in deposition on other metals as a protective layer. Cadmium belongs to Transition metal family of the periodic table with atomic number 48 and atomic mass 112.4g $mol/^{-1}$. It is melting point is 321 ºC, and the boiling point is 767 ºC. By nature, Cadmium has high corrosive resistivity that's why it is used for plating other metals in electronics and aerospace industries [8].

A very large amount of cadmium is released into the environment [9]. Cadmium is released into rivers through weathering of rocks, forest fires, *etc*. and also through human activities like electroplating, manufacturing, *etc*. Cadmium can cause many health problems like damage to the nervous system, immune system, psychological problems as well as reproductive failure and even infertility. So, it is essential to remove it to avoid human health problems and environmental deterioration. A most economical and eco-friendly way to treat this pollution is bioremediation.

Cadmium Toxicity:

Health Effects: The International Agency for Research on Cancer (IARC) has classified cadmium and cadmium compounds as carcinogenic to humans (IARC 1993 and 2009). According to IPCS 1992 and WHO 2010 in humans, exposed to cadmium mainly occurs by consuming contaminated food and through inhalation by workers in the metal industries. Cadmium can easily bind to respiratory enzymes [10] and can cause cancer [11].

Plants act as a carrier of various cadmium salts (Especially those having great solubility in water) into the food chain [12]. Plants which are growing in polluted soil can easily take up heavy metals that may then enter the food chain [13]. In selected vegetables, Cd concentration in soils and food crops was above permissible limits [14]. So from their report, it can be concluded that consuming such vegetables may lead to cadmium toxicity in humans as well as animals. People who are living near the industrial area are more prone to toxicity, which can severely damage their lungs. People who like fishes such as shellfish in their diet regularly are at more risk of cadmium exposure (ATSDR 2008) **Table 1**.

TABLE 1: SHOWING HEALTH EFFECTS OF CADMIUM

S. no.	Problems	References
1	Bone fracture	15
2	Reproductive failure and possibly even infertility	16
3	Kidney Damage	17
4	Shortness of breath, lung edema	18
5	Cancer development	19
6	Psychological disorders	20
7	Hypertension, renal damage, testicular atrophy	6

Environmental Effects: cadmium exposure to the environment is a threat now a day's. This exposure is mainly from the mining industries **Table 2**.

TABLE 2: SHOWING EFFECTS OF CADMIUM ON GROWTH OF PLANTS

S. no.	Problems	References
1	Effects tissues of aerial parts of plants	21
3	Inhibits cell division in leaf	22
4	Causes abnormal mitosis division in plant	23

Bioremediation: Bioremediation is an act of removing pollutants from a contaminated site with the help of microorganisms as well as plants. Using microorganisms for the treatment of polluted soils is a more eco-friendly and economical approach in the field of bioremediation.

According to the EPA, bioremediation is a "technique which uses naturally occurring microorganisms to break down hazardous substances into less toxic or non-toxic substances." There are two techniques of bioremediation *in situ* and *ex-situ* **Fig. 1**.

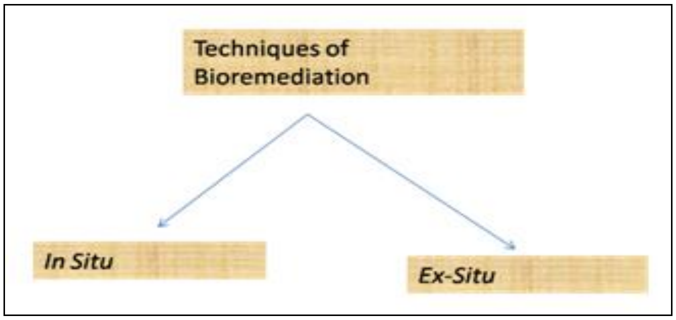

FIG. 1: TECHNIQUES OF BIOREMEDIATION

***In-situ* Bioremediation:** Involves the onsite treatment of the contaminated effluent. We need not remove soil or water samples from the site. The pollution by heavy metal on the site can be directly removed. In this type of remediation naturally occurring microorganisms are stimulated to show their activity against the heavy metals [24, 25]. Since it uses naturally occurring microorganisms so it is not cheaper as well as harmless nor it produces harmful byproducts in the environment. It mainly involves the onsite treatment of polluted substances. These techniques are very cheap than ex-situ bioremediation techniques, as no disturbance to its structure. Dyes, heavy metals, chlorinated solvents can be treated with the help of this technique [26, 27]. The suitable conditions required for successful *in-situ* bioremediation are moisture content, pH, temperature, nutrient availability, the status of electron acceptor, *etc*. [28] The advantages of in-situ bioremediation involves minimal exposure of public and site personnel, minimal site disruption, low cost, simultaneous treatment of contaminated water in soil **Fig. 2**.

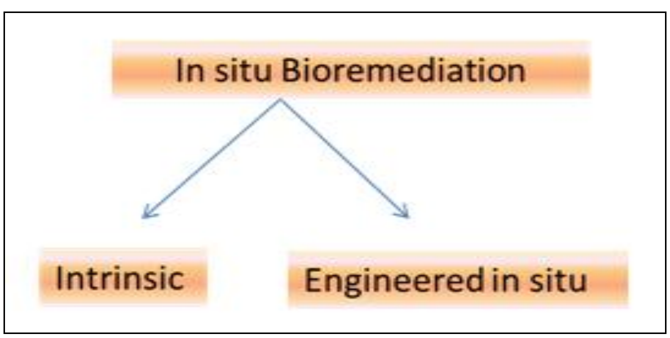

FIG. 2: TYPES OF *IN-SITU* BIOREMEDIATION

Intrinsic bioremediation is simply enhancing microflora on the site of remediation where pollution of heavy metals occurred.

Engineered *in-situ* is introduced the systems have to be incorporated to enhance the microflora on the site.

***Ex-situ* Bioremediation:** As the name suggests, *ex-situ* means outside, so it involves the removal of the contaminated effluent to be treated elsewhere. The technique of land farming was demonstrated by the US Army Corps of Engineers, which showed the enhanced remediation of petroleum contaminated soils. Microorganisms which are used to perform the function of bioremediation are well known as bioremediation.

Types:

Phytoremediation: It is an emerging technique that mainly depends on the use of physical, chemical, and biochemical interactions of plans in contaminated sites for the treatment/mineralization of pollutants. There are several mechanisms which are involved in phytoremediation. These mechanisms mainly depend upon the type of pollutant as a different process is needed for different contaminants. The pollutants like toxic heavy metals are removed by extraction, while pollutants like hydrocarbons and chlorinated compounds are removed by degradation, rhizoremediation, and volatilization [29, 30]. There are many important factors that should be kept in mind while choosing a plant as a phytoremediator like root system – which may be fibrous or tap depending on the toxicity of pollutant, to which extent the pollutant is toxic to plant, what will be plant growth rate in the presence of pollutant, and how much time is required to achieve the desired level of remediation. The use of Plant Growth Promoting Rhizobacteria was reported, which might play an important role in phytoremediation. Phytoremediation of cadmium was done with the help of three indigenous plants *Eleusine indica*, L. (KB-1), *Ageratum conyzoides*, L. (KB-2), and *Euphorbia hirta* (KB-3) and subsequently, 58.8, 52.2, 51.8% of reduction of cadmium concentration was observed.

Phytoextraction: Phytoextraction involves a different a mechanism of plants which remove toxic elements, *i.e*. heavy metals from soil or water, metals whose density is very high and may be toxic to organisms when present in low concentrations. The mechanism mainly depends upon the ability of plants to translocate the pollutants from roots to aboveground shoots or leaves. Natural ability and efficiency of a plant is the basis of Phytoextraction [31, 32]. Phytoextraction of cadmium was performed with the help of plant *Brassica juncea*, and 60% reduction was observed in Cd concentration [33].

Microorganisms for Bioremediation: Besides plants, the minute species which cannot be seen by the naked eye (visible in microscopy) can be used as bioremediation to remove toxic pollutants from the environment. The naturally present microorganisms which are indigenous or extraneous, are used as agents for bioremediation. The nature of micro mainly relies on the type of polluting agent. Proper selection criteria of organisms should be selected as different species show different survival rate in different concentrations of pollutants. Bioremediation can be achieved by mainly two processes, i.e. either naturally or through intervention process, as reported by [34].

Classification of Microbes- Microbes involved in bioremediation are –

(1) Aerobic: Aerobic bacteria are those who need oxygen for their growth and survival. The aerobic bacteria which are involved in bioremediation are *Mycobacterium, Pseudomonas putida, P. diminuts, Sphingomonas, Rhodococcus, etc*. These microbes decontaminate the sites by using the pollutants like heavy metals, pesticides, and hydrocarbon compounds as their carbon and energy sources.

(2) Anaerobic: Anaerobic bacteria are those who cannot grow in the presence of oxygen and also the use of these bacteria is not as frequent as aerobic ones for bioremediation purpose. The main approach, which is used for anaerobic bioremediation is *in-situ* [35].

(3) Methylotrophs: These bacteria come under the class of Aerobic bacteria that grow utilize methane as a source of energy and carbon. It has a wide range of substrate and reported against a huge range of pollutants. In Methylotrophs the enzyme methane mono-oxygenase was reported for its activity and stability against a wide range of pollutants

(4) Ligninolytic Fungi: The fungi also can degrade a wide range of toxic pollutants, for example, White rot fungus such as *Phanaerochaete chrysosporium*. White rot fungi degrade organic pollutants in soil and effluents. *Candida* degrades formaldehyde. Common substrates which are used are straw, corn cobs, or sawdust.

Mycoremediation (Using Fungi): Myco-remediation is bioremediation in which fungi species are used to decontaminate the pollutant or to target a specific pollutant. Scientists experimented in 1999; a plot of diesel oil contaminated soil was inoculated with mycelia and succeeded in its decontamination. Fungi like white rot fungus can degrade toxic pollutants [36]. Fungi of the genera *Penicillium, Aspergillus,* and *Rhizopus* have been studied as an efficient bioremediator for the removal of heavy metals and. Sometimes microfiltration term is used in this process in the mycelium of fungi is used to filtrate the toxic compounds from water in the soil [37, 38]. In **Table 3**, few of the microorganism has been shown through which bioremediation has been achieved against heavy metal [36]. Ligninolytic Fungi such as *Phaneraero chaetechrysosprium* can degrade a wide range of pollutants [39] **Table 3**.

TABLE 3: MICROORGANISMS HAVING the ABILITY TO DEGRADE HEAVY METALS (SOURCE: VIDALI 2001)

S. no.	Elements	Microorganisms
1	Zn, Cu, Cd	*Bacillus sp. Pseudomonas aeruginosa* [40]
2	CO, Ni, Cd	*Citrobacter sp.* [40]
3	Cd, Pb	*Phormidium valderium* [41, 42]
4	Pb, Au, Zn, Cd	*Chlorella vulgaris* [40]
5	Cd, Zn, Ag	*Aspergillus niger* [40]
6	Zn, Cu, Cd	*Pleurotus ostreatu sp.* [40]
7	Hg, Ag, Cd	*Rhizopus arrhizus* [43]

The specific features of microorganisms like survival and growth at extreme environmental conditions like temperature, heat, and desert conditions make them suitable for the removal of toxic pollutants from the environment. Many fungi and bacteria are known to be used for bioremediation of Industrial effluent. Different species of *Pseudomonas, Bacillus, Aspergillus, Sporophyticus* have been reported as efficient chromium and nickel reducers. The first patent for the strain *Pseudomonas putida* for bioremediation was filed in 1974 which was able to degrade petroleum [34]. Some microorganisms have resistance against the heavy metals and can grow in the heavy metal-rich environment. A metal tolerant bacterium that has the capability of removing Copper, Chromium, and arsenic from treated wood was isolated [44]. These microorganisms have different mechanisms from each other to tolerate the uptake of heavy metals. Studies were conducted on biosorption of cadmium by *Pseudomonas and* concluded that this species could tolerate up to 50 mg/L of cadmium [45].

Bioremediation in the rice plant by metal resistance *Ochrobactrum* sp. and *Bacillus* sp was done recently [46]. *Ralstonia eutropha* has been modified genetically to decrease the toxic effect of the Cd (II) in the contaminated sites [34]. For the efficient elimination of Zn(II) and Cd (II, *Saccharomyces cerevisiae* acts as a bio sorbent [47, 48]. *Cunninghamella elegans* was reported as promising organism against heavy metals released by textile wastewater [49]. Recently cadmium and chromium metals are checked for their bioremediation with the help of Earthworm *Eisenia fetida* who showed the tolerance up to 0.06 and 0.14 mg/l respectively [50]. Among the wide range of microorganisms used for bioremediation, there are many fungal strains that are used for the purpose. *A. niger* is used for the bioremediation of chromium from the tannery industry [51]. *Aspergillus fumigates* has excellent efficiency in removing heavy metals [52].

Different groups all over the world are involved in search of microbial strains that can be helpful for bioremediation. In Brazil, China and other countries where Industrialization is increasing with the higher pace the hazardous contaminants are also increasing at a similar pace. In addition to the development of various biosensors, the work has also been started where the organism's resistant to specific metal is checked to show resistant against other heavy metals also. Cadmium resistant *Stenotrophomonas sp.* showed resistant to Selenium and Copper [53].

Recently Heavy metal resistant bacterial strain from Industrial and Agricultural areas in Mauritius was isolated, which are helpful in bioremediation [54]. A wide range of accumulation of cadmium was regulated by *Escherichia coli* [55]. *Pseudomonas* strain was modified with the pMR68 plasmid with novel genes (mer) made that strain resistant to mercury [56]. *Klebsiella pneumonia* M426 was modified to precipitate the mercury [57].

Many laboratories throughout the nation are involved in isolation and identification of heavy metal resistant bacteria. Physiochemical methods were reported to be used as an approach to reduce the heavy metals from contaminated site [58]. The strain has successfully reduced Cr and Ni. Bacterial strains of *Pseudomonaputida*, *Pseudomonas aeruginosa*, and *Bacillus sp.* were found to reduce Chromium (VI) content of the textile Industry effluent [59].

In addition to bacterial strains, many fungal strains have also been reported showing heavy metal absorption efficiency. Fungal strains from Sugar mill of Cheyyiar Cooperative Sugar Mill, Thiruvannamalai district were isolated and utilized them for the bioremediation of sugar mill effluent [60].

The use of potent microorganisms that are resistant to activities of heavy metal is very important [61]. During past years strains have been isolated like *Staphylococcus aureus* especially for cadmium[62, 63]. Cadmium resistant bacteria, *i.e. Pseudomonas aeruginosa* from waste processing plant sludge effluent was isolated and was subjected to induction of mutation by acridine orange and acriflavine and 94.7% of cadmium removal was achieved [64]. The strains *E. coli* and *P. syringae* were studied for the removal of cadmium by respectively [65, 66].

Many studies have been carried out in the past for the isolation and identification of bacterial strains that are resistant to cadmium. *Pseudomonas putida*, *Pseudomonas aeruginosa*, *Pseudomonas fluoroscenes*, *E. coli*, *Comamonas testosterone*, *Klebsiella planticola*, *Staphylococcus aureus*, *Bacillus subtilis*, *Lactobacillus plantarium*, *Staphylococcus lugdunensis*, *Ralstonia metallidurans*, *Alcaligenes eutrophus*, *Serratialique faciens*, and *Bacillus thuringensis* were the common species of bacteria that have been studied most regarding their cadmium accumulation ability [67].

Pseudomonas putida degrades about more than 80% of cadmium in less than 5 min at pH from 5.0 - 7.5 [68]. *Alcaligenes eutrophus* CH_{34} bacterial strain was grown on a pilot - plant. It degrades up to 90% of the cadmium [69]. The bacterial strains were able to degrade cadmium, but their efficiency depends upon the induced proteins that are produced in the cells [70]. *Streptomyces rimosus* has a cell wall which contains anionic groups such as phosphate amino, carboxyl, *etc*. whose ability to adsorb cadmium is very high [71].

Microorganisms used biosorption method to remove the toxic metals which are present in water and streams. *Bacillus licheniformis* and *Bacillus laterosporus* were two bacterial strains that remove cadmium from water. The temperature of 60 ºC did not affect the ability of these strains to degrade cadmium. The maximum capacities of non- living cells of these strains to remove cadmium were 142.7 and 159.5 mg/g respectively [72]. Bacterial strain *Rhodotorula* sp. Y11 was able to degrade cadmium. Its capacity was about 11.38 mg/g [73].

Recent studies revealed that *Staphylococcus xylosus* and *Pseudomonas* sp. were the bacterial strains whose ability to degrade cadmium was 278 and 250 mg/g respectively [74]. A bacterial strain KUCd1 was isolated, which closely resembled with *Pseudomonas aeruginosa*. *Pseudomonas aeruginosa* strain KUCd1 showed its ability to remove about 75% and 89% of cadmium [75]. *Spirogyra* and *Oscillatoria sp*. were studied for sequestration of cadmium from industrial wastewater [76].

Phytoremediation: Besides of microorganisms plants can also be used to clean the residues of toxic heavy metals [77] **Table 4**.

TABLE 4: LIST OF PLANTS USED FOR REMEDIATION OF HEAVY METALS

S. no.	Name of Plants	Heavy metals
1	*Brassica juncea*	Lead and cadmium [78]
2	*Claytonia perfoliata*	Cadmium [79]
3	*Cerastiumarvense*	Cadmium [79]
4	*Stellariacalycantha*	Cadmium [79]
5	*Lupinus Albus*	Arsenic and Cadmium [80]
6	*Allium schoenoprasum*	Cadmium [81]
7	*Digitalis purpurea*	Cadmium [82]
8	*Pterisvittata*	Arsenic and cadmium [83]
9	*Melilotusofficinails*	Hydrocarbons [84]
10	*Populustermula*	Lead and cadmium [82]

CONCLUSION: The presence of heavy metals in the food chain has become a threat to human and wildlife as it can cause many severe diseases as discussed above. The heavy metals as fumes are also degrading the environment. So to remove all these threats, there is a need for the implication of proper treatment processes which can minimize the health and environmental impacts of toxic heavy metals.

There are many other physical processes by which above said a goal could be achieved, but they are expensive and have low efficiency for the removal of compounds. The eco-friendly techniques such as bioremediation, phytoremediation, Phytoextraction, and Mycoremediation, *etc*. offer a great choice to eliminate these contaminates permanently from the environment and clean it.

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REFERENCES:

1. Sundar K, Vidya R, Mukherjee A and Chandrasekaran N: High chromium tolerant bacterial strains from Palar River Basin: Impact of Tannery Pollution. Res J Environ Earth Sci 2010; 2: 112-17.
2. Choudhury A.R and Pradhan S: Role of potentially important microbes in bioremediation.Sci Cult 2011; 77: 324 -30.
3. Safahieh A, Abyar H, Roostan Z,Zolgharnein H and Mojoodi F: Isolation and characterization of Pseudomonas resistant to heavy metals and poly aromatics hydrocarbons (PAHs) from Persian Gulf sediments. Afr J Biotechnol 2012; 11: 4418-23.
4. Zaki S and Farag S: Isolation and molecular characterization of some copper biosorped strains. Int J Environ Sci Tech 2010; 7(3): 553-60.
5. Zeng X, Tang J, Liu X and Jiang P: Isolation, identification and characterization of cadmium resistant *Pseudomonas aeruginosa* strain E1. J Cent South Univ Technol 2010; 16: 416-21.
6. Leyva-Ramos R, Rangel-Mendez JR, Mendoza-Barron J, Fuentes- Rubio L and Guerrero-Coronado RM: Adsorption of cadmium(II) from aqueous solution on activated carbon. Water Sci Technol 1997; 35(7): 205-11.
7. Dianati-Tilaki RA, Hahvi AH, Shariat M and Nasseri S: Study of cadmium removal from environmental water by biofilm covered granular activated carbon. Iranian J Public Health 2004; 33(4): 43-52.
8. Herrero R, Lodeiro P, Rey-Castro C, Vilariño T and Sastre de Vicente ME: Removal of inorganic mercury from aqueous solutions by biomass of the marine macroalga *Cystoseira baccata*. Water Res 2005; 39: 3199-10.

9. Beard SJ, Hashim R, Hernandez J, Hughes M and Poole RK: Zinc (II) tolerance in *Escherichia coli* K-12: evidence that the zntA gene (o732) encodes a cation transport ATPase. Mole Microbiol 1997; 25: 883-91.
10. Nies DH and Silver S: Ion efflux systems involved in bacterial metal resistances. J Ind Microbiol 1995; 14: 186-99.
11. Banjerdkji P, Vattanaviboon P and Mongkolsuk S: Exposure to cadmium elevates expression of genes in the oxy R and Ohr R regulons and induces cross-resistance to peroxide killing treatment in *Xanthomonas campestris*. Appl EnvironMicrobiol 2005; 71(4): 1843-49.
12. Daud MK, Variath MT and Ali S: Cadmium-induced ultra-morphological and physiological changes in leaves of two transgenic cotton cultivars and their wild relative. Journal of Hazardous Materials 2009; 168: 614-25.
13. Williams PN, Lei M and Sun G: Occurrence and partitioning of cadmium, arsenic and lead in mine-impacted paddy rice. Hunan China, Environmental Science and Technology 2009; 43(3): 637-42.
14. Chaudhry TM, Hayes WJ, Khan AG and Khoo CS: Phytoremediation focusing on accumulator plants that remediate metal contaminated soils. Australasian Journal of Ecotoxicology 1998; 4: 37-51.
15. Kazantzis G: Renal tubular dysfunction and abnormalities of calcium metabolism in cadmium workers. Environment Health Perspectives1979; 28: 155-59.
16. Piasek M and Laskey JW: Effects of *in-vitro* cadmium exposure on ovarian steroidogenesis in rats. J Appl Toxicol 1999; 19: 211-17.
17. Barbier O, Jacquillet G, Tauc M, Cougnon M and Poujeol P: Effect of heavy metals on and handling by, the kidney. Nephron Physiol 2005; 99: 105-08.
18. Seidal K, Jorgensen N, Elinder CG, Sjogren B and Vahter M: Fatal cadmium-induced pneumonitis. Scand J Work Environ Health 1993; 19: 429-31.
19. Waalkes MP: Cadmium carcinogenesis. NCBI Mutat Res 2003; 533(1-2): 107-20.
20. Fattal O, Budur K, Vaughan AJ and Franco K: Review of the literature on major mental disorders in adult patients with mitochondrial diseases. Psychosomatics 2006; 47: 1-7.
21. Verbruggen N, Hermans C and Schat H: Molecular mechanisms of metal hyperaccumulation in plants. New Phytol 2009; 181: 759-76.
22. Tuan A, Tran, Vassileva V, Petrov P and Losanka P: Cadmium-induced structural disturbances in *Pisum sativum* leaves are alleviated by nitric oxide. Turkish Journal of Botany 2013; 37: 698-707.
23. Aery NC and Sarkar S: Metal species vis-à-vis seed germination and early seedling growth responses in soybean. J Chem Bio PhySci Sec 2012; 2(2): 763-69.
24. Vidali M: Bioremediation: An overview. Pure Applied Chemistry 2001; 73: 1163-172.
25. Evans GM and Furlong JC: Environmental Biotechnology Theory and Application. John Wiley & Sons, 2003.West Sussex, England.
26. Kim S, Krajmalnik BR, Kim JO and Chung J: Remediatiom of petroleum hydrocarbon contaminated sites by DNA diagnosis based bioslurping technology. Science Total Environment 2014; 497: 250-59.
27. Roy M, Giri AK, Dutta S and Mukherjee P: Integrated phytobial remediation for sustainable management of arsenic in soil and water. Environmental International 2015; 75: 180-98.
28. Philip JC and Atlas RM: Bioremediation: applied microbial solutions for real world environmental cleanup. American Society for Microbiology (ASM) Press, Washington 2005; 139-36.
29. Meagher RB: Phytoremediation of toxic elemental organic pollutants. Curr Opin Plant Biol 2000; 3: 162.
30. Kuiper I, Lagendijk EL, Bloemberg GV and Lugtenberg BJJ: Rhizoremediation-A beneficial plant-microbe interaction. Mol Plant-Microbe Interact 2014; 17: 6-15.
31. Salt DE, Blaylock PBA, Nanda K, Dushenkov V, Ensley BD and Raskin I: Phytoremediation: A novel strategy for the removal of toxic metals from the environment using plants. Biotechnol 1995; 13: 468-74.
32. Salt DE, Pickering IJ, Prince RC, Gleba D, Dushenkov S, Smith RD and Raskin I: Metal accumulation by aquacultured seedlings of Indian Mustard. EnvironSci Techno 1997; 31(6): 1636-44.
33. Kathal R, Malhotra P and Chaudhary V: Phytoremediation of Cadmium from Polluted Soil. J Bioremediat Biodegrad 2016; 7: 376.
34. Latha A, Sandeep P and Reddy S: Review on Bioremediation- Potential Tool for Removing Environmental Pollution. International Journal of Basic and Applied Chemical Sciences 2013; 3(3): 21-33.
35. ITRC. Technical and Regulatory Guidance Document for Constructed Treatment Wetlands. Interstate Technology and Regulatory Council 2003.
36. Prasad and Freitas: Removal of toxic metals from solution by leaf, stem and root phytomass of *Quercus ilex* L. (Holly Oak).Journal of Environment Pollution 1999; 110: 277-83.
37. Volesky B and Holan ZR: Biosorption of heavy metals. Biotechnol Prog 1995; 11: 235-50.
38. Huang C and Huang CP: Application of *Aspergillus oryzae* and *Rhizopus oryzae* for Cu (II) removal. Water Re 1996; 30: 1985-90.
39. Novotny C, Erbanova P, Sasek V, Kubatova A, Cajthman T, Lang E, Krahl J and Zadrazil F: Extracellular oxidative enzyme production and PAH removal in soil by exploratory mycelium of white rot fungi. Biodegradation 1999; 10: 159-68.
40. Gunasekaran P, Muthukrishnan J and Rajendran P: Microbes in Heavy Metal Remediation. Indian Journal of Experimental Biology 2003; 935-44.
41. Gabriel J, Kofronova O, Rychlovsky P and Krenzelok M: Accumulation and effect of cadmium in the wood rotting basidiomycete, Daedaleaquercina. Bulletin of Environmental Contamination and Toxicol 1996; 383-90.
42. Gabriel J, Mokrejs M, Bily J and Rychlovsky P: Accumulation of heavy metal by some Wood rooting fungi. Folia Microbiologica 1994; 39: 115-18.
43. Favero N, Costa P and Massimino ML: uptake of cadmium by basidiomycete Pleurotus ostreatus. Biotechnology Letters 1991; 701-04.
44. Carol A and Clausen: Isolating metal-tolerant bacteria capable of removing copper, chromium, and arsenic from treated wood. Waste Manage Res 2000; 18: 264-68.
45. Yadav H, Nanganuru and Korrapati N: Studies on Biosorption of cadmium by *Pseudomonas putida*. International Journal of Engineering Research and Applications 2012; 2(3): 2217-19.
46. Pandey S, Ghosh PK, Ghosh S, De TK and Maiti TK: Role of heavy metal resistant Ochrobactrum sp. and Bacillus sp. strains in bioremediation of a rice cultivar and their PGPR like activities. J Microbiology 2013; 51(1): 11-17.
47. Chen C and Wang JL: Characteristics of Zn^{2+} biosorption by *Saccharomyces cerevisiae*. Biomed Environ Sci 2007; 20: 478-82.
48. Talos K, Pager Conk S, Majdik C, Kocsis B, Kilar F and Pernyeszi T: Cadmium biosorption on native

Saccharomyces cerevisiae cells in aqueous suspension. Acta Univ Sapientiae. Agric Environ 2009; 1: 20-30.

49. Tigini V, Prigione V, Giansanti P, Mangiavillano A, Pannocchia A and Varese GC: Fungal biosorption, an innovative treatment for the decolorisation and detoxification of textile effluents. Water 2010; 2: 550-65.
50. Aseman-Bashiz E, Hosseinali A, Hossein A, Leila I and Mostafaii GR: Bioremediation of the soils contaminated with cadmium and chromium, by the earthworm *Eisenia fetida*. Brazilian Journal of Chemical Engineering 2014; 33(4): 827-34.
51. Nouri M, Sepehr S, Nasseri M, Mazaheri A and Maghmaian K: Chromium removal from tannary Industries effluent by *Aspergillus oryzae*. Iran J Environl Health Sci Engin 2005; 2: 273-79.
52. Shazia I, Uzma, Sadia GR and Talat A: Bioremediation of heavy metals using isolates of filamentous fungus *Aspergillus fumigatus* collected from polluted soil of Kasur, Pakistan. International Research Journal of Biological Sciences 2013; 2: 1-8.
53. Antonioli P, Lampis S, Chesini I, Vallini G, Rinalducci S, Zolla L and Righetti PG: *Stenotrophomonas maltophilia* SeITE02, a new bacterial strain suitable for bioremediation of selenite contaminated environmental matrices. Appl Environ Micobiol 2007; 73: 6854-63.
54. Hookoom M and Puchooa D: Isolation and Identification of heavy metals tolerant bacteria from industrial and agricultural areas in Mauritius. Curr Res Microbiol Biotech 2013; 1(3): 119-23.
55. Mejare M and Bulo L: Metal binding proteins and peptides in bioremediation and phytoremediation of heavy metals. Trends Biotechnol 2001; 19: 67-73.
56. Sone Y, Mochizuki Y, Koizawa K, Nakamura R, Pan-Hou H, Itoh T and Kiyono M: Mercurial resistance determinants in Pseudomonas strain K-62 plasmid pMR68. AMB Express 2013; 3: 41.
57. Essa AM, Mcaskie LE and Brown NL: Mechanisms of mercury bioremediation. Biochem Soc Trans 2002; 30: 672-74.
58. Kapoor A and ViraraghvanT: Fungal biosorption-An alternative treatment option for heavy metal bearing wastewater: A review. Bioreso Technol 1995; 53: 195-06.
59. Deepali: Bioremediation of Chromium (VI) from textile industry’s effluent and contaminated soil using *Pseudomonas putida*. Iranica Journal of Energy and Environment 2011; 2(1): 24-31.
60. Buvaneswari S, Damodarkumar S and Murugesan S: Bioremediation studies on sugar-mill effluent by selected fungal species. Int J Curr Microbiol App Sci 2013; 2(1): 50-58.
61. Shakibaie MR, Khosravan A, Farmhand A and Zare S: Application of metal resistant bacteria by mutational enhancement technique for bioremediation of copper and zinc from industrial wastes. Iran J Environ Health. Sci Eng 2008; 5: 251-56.
62. Novick RP and Roth C: Plasmid-linked resistance to inorganic salts in Staphylococcus aureus. Bacteriology 1968; 95: 1335-42.
63. Mitra RS, Gray RH, Chin B and Berstein IA: Molecular mechanisms of accumulation in *Escherichia coli to* toxic levels of cadmium. Journal of Bacteriology 1975; 121: 1180-88.
64. Jabbari A, Kermani N, Faezi G, Mohammad, Khosravan A, Farahmand A and Mohammadreza S: Cadmium bioremediation by metal-resistant mutated bacteria isolated from active sludge of industrial effluent. Iran J Environ Health Sci Eng 2012; 7: 279-86.
65. Cohen I, Bitan R and Nitzan Y: The effect of zinc and cadmium ions on *E. coli*. Microbios 1991; 68: 157-68.
66. Cabral JP: Selective binding of metal ions to P*seudomonas syringaecells*. Microbios 1992; 71: 47-53.
67. Amoozegar MA, Ghazanfari N and Didari M: Lead and cadmium bioremoval by Halomona ssp., an exopolysaccharide producing halophilic bacterium. Prog Biol Sci 2012; 2: 1-11.
68. Pardo P, Rauret G and Lopez-Sanchez JF: Analytical approaches to the determination of phosphorus partitioning patterns in sediments. J Environ Monitor 2003; 5: 312-18.
69. Mahvi A and Diels HL: Biological removal of cadmium by Alcaligeneseutrophus CH34. nt J Environ SciTechnol 2004; 1(3): 199-04.
70. Chovanova K, Sladekova D, Kmet V, Proksova M, Harichova J, Puskarova A, Polek B and Ferianc P: Identification and characterization of eight cadmium resistant bacterial isolates from a cadmium-contaminated sewage sludge. Biologia Bratislava 2004; 59(6): 817-27.
71. Selatnia A, Bakhti A, Madani L, Kertous and Mansouri Y: Biosorption of Cd^{2+} from aqueous solution by a NaOH-treated bacterial dead Streptomyces rimosus biomass. Hydrometallurgy 2004; 75: 11-24.
72. Zouboulis AI, Matis KA, Loukidou MX and Karapantsios TD: Diffusion kinetic study of cadmium (II) biosorption by Aeromonascaviae. J Chem Technol Biotechnol 2004; 79: 711-9.
73. Li Z and Hongli Y: Characterization of cadmium removal by Rhodotorula sp. Y11. Applied Microbiology and Biotechnology 2006; 73: 458-63.
74. Ziagova M, Dimitriadis G, Aslanidou D, Papaioannou X, Tzannetaki EL and Liakopoulou-Kyriakides M: Comparative study of Cd (II) and Cr(VI) biosorption on *Staphylococcus xylosus* and Pseudomonas sp. in single and binary mixtures. Biores Technol 2007; 98: 2859-65.
75. Sinha S and Mukherjee SK: *Pseudomonas aeruginosa* KUCD1, a possible candidate for cadmium bioremediation. Braz J Microbiol 2009; 40: 655-62.
76. Brahmbhatt NH, Patel VR and Jasraj RT: Bioremediation potential of Spirogyra Sps and Oscillatoria sps for cadmium. Asian Journal of Biochemical and Pharmaceutical Research 2012; 2(2): 102-07.
77. Girma G: Microbial bioremediation of some heavy metals in soils: an updated review. Indian J Sci Res 2012; 6(1): 147-61.
78. Raskin I, Smith RD and Salt DE: Phytoremediation of metals: Using plants to remove pollutants from the environment. Curr Opin Biotechnol 2005; 8(2): 221-26.
79. Institute of Environmental Research and Education. Vashon heavy metal phytoremediation study sampling and analysis strategy 2003.
80. Esteban E, Carpena RO and Meharg AA: High-affinity phosphate/ arsenate transport in whitelupin (Lupinusalbus) is relatively insensitive to phosphate status. New Phytologist 2003; 158: 165-73.
81. Barazani O, Dudai N, Khadka UR and Golan-Goldhirsh A: Cadmium accumulation in *Allium schoenoprasum* L. grown in an aqueous medium. Chemosphere 2004; 57: 1213-18.
82. McCutcheon SC and Schnoor JL: Photoremediation: Transformation and Control of Contaminants. New Jersey: Wiley-Interscience, 2003:714-20.
83. Caille B, Vauleon C and Leyval C: Metal transfer to plants grown on dredged sediment: Use of radioactive isotope Hg-203 and titanium. Sci Total Environ 2005; 341(13): 227-39.

84. Christensen-Krish KM: Phytoremediation and wastewater effluent disposal: Guidelines for landscape planners and designers.1996. Unpublished master's project, Department of Landscape Architecture, University of Oregon, Eugene, 238.

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