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**Heavy Metals in Health Issues and Microbes in Remediation: A Review**

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**Abstract:**

Industrializations are the major source of environmental pollution. The waste discharge from several industries can create an immense impact on water bodies which can disrupt the balance of several parameters of it. Too much accumulation of heavy metals through waste water can hamper human health as well as food chain. Thus several diseases take place in daily life because of accumulation of several heavy metals. These can accelerate generation of generation of reactive oxygen species (ROS) which is the ultimatum of age related disease like Parkinson disease, Alzheimer’s disease etc. This accumulation is not only limited to ROS production it has the ability to hamper immune system abruptly. To get rid of these bioremediation can be an alternative and efficient way. With the help of several micro-organismsit can dispose these heavy metals. This review focuses on several heavy metal related diseases as well as bioremediation processes by microorganisms. It includes the list of algae and fungi which is participating in bioremediation and which kind of metals they are able to remove.

**1.Introduction:**

Increase in Industrialization and Urbanization are enhancing environmental pollution [1]. Arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), mercury (Hg), silver (Ag), zinc (Zn) are known as heavy metals because the density of those metals are more than 5 gm/cm3. Heavy metals are the main source of environmental pollution. Being non-biodegradable and xenobiotic compound it is really tough to get rid of heavy metals thus results in accumulation in food chain. The accumulation can be the consequence of environmental pollution as well as several health issues.[2].

Textile industries consume lots of water and chemicals for processing thus is discharge chemicals which are left over by the product and as a result it become the major source of water pollution and accumulation heavy metals [3]. It is hampering several parameters of water body like pH, temperature, colour, BOD(Biochemical Oxygen Demand), COD (Chemical oxygen demand) etc. [3].

Bioremediation is a process to remove contamination. Heavy metal can cause environmental pollution. It is relatively low cost, low-technology techniques which is high public acceptance and a good alternative technology to cleanup. Bioremediation is becoming handful technique of several sites of worldwide including Europe. It has been observed that Bioremediation has great potential to remove contaminations of certain types. Unfortunately the disadvantages and advantages are not clearly known for those who will be dealing with it [4].

In this review we will be discussing about several health issues due to exposure of heavy metals and how bioremediation is use to get rid of heavy metals causing from environmental pollution. Moreover we will be discussing how microorganism such as algae and fungi are responsible for enhancing the process of heavy metal removal.

**2.Principle of Bioremediation:**

Composting and waste water treatments are the old and familiar term of environmental technology.Recently molecular biology and ecology is including several biological processes, accomplishment of these studies include cleanup of water pollution and land areas. It can be defined that bioremediation is under controlled condition where organic wastes can be degraded biologically. It uses microorganisms like algae, fungi, bacteria etc. [5]. Usually algae,fugue, bacteria have the potential to degrade organic substances hazardous for human health. These microorganisms transform organic compounds through reactions which take place as a metabolic process. Microorganisms catalyze the process of degradation known as bio-augmentation. Bioremediation has the capability to reduce the exposure risk for a clean up personnel. It is more economical than many other traditional methods like incineration.

As it is mostly dependent upon biological activity and natural attenuation it is more acceptable and other methods. For most of the time the process runs under aerobic condition but anaerobic condition is reported to be more favorable for micro-organisms to degrade[5].

**3.Bioremediation System and process:**

Ex situ and in situ are the broad classifications of bioremediation procedure. Ex situ process includes different technology to remove the contaminant and in situ remove the contaminant at the place itself. It has been observed in many studies that in situ process has many advantages over physical and chemical remediation [6].

**4.Heavy metals in environment:**

Due to industrialization the exposure of heavy metal to the environment is increasing. Thus the process can alter health of soil, aquatic system as well as human health.The contaminations can be removed either by plants known as phytoremediation or by microbes called bioremediation. Scientists are approaching to reduce the contamination by releasing the pollutants. Heavy metals mostly found in soil are zinc(Zn), cadmium(Cd), copper(Cu), lead(Pb) etc. Zinc(Zn) reported to be the most abundant pollutant creating phytotoxicity on the other hand it has been observed that human health mostly endangered by cadmium(Cd). Accumulation of these heavy metals may inhibit progressive degradation of many organic substances. Thus it is important to make efficient removal of these contaminants. Siderophores can produce iron complexing molecules in absence of iron molecules. These microorganisms have high affinity towards heavy metals. Studies reported that in case of *Pseudomonas aeruginosa*and*Alcaligeneseutrophus* many siderophore syntheses can be induced by heavy metals even in high concentration or iron. Negative and constitutive siderophore mutants may results into the solubilisation of metals.The heavy metal resistance, bioprecipitation capacity, and improved soil flocculation are the cause to develop bioremediation method for heavy-metal-contaminated soils.*A eutrophus* present in the soil has ability to treat heavy metals contaminants in soil. It helps to transfer contaminating metals to the bacterial cell wall from soil particles. Then the metal loaded bacteria can be removed easily from water suspension either by flotation or flocculation process [7].

**5.Heavy metals in health issues:**

Exposure to the heavy metal can be the cause of several diseases. Not only normal human health it can cause effect upon the foetus of a pregnant woman. Sometimes it can disrupt the metabolic process of a body. Most common source of heavy metal exposure can be cigarettes. Passive or active smoking leads to the exposure to heavy metal cadmium (Cd). Accumulation of heavy metals results into neurogenetic disorders. Biomagnification plays a role to increase health risk. Depending upon metal toxicity acute and chronic may take place. Absorbing too much metal can increase free radicals which increases free radicals thus oxidative stress increases [8].

Heavy metals can suppress immune system as a result of exposure to heavy metals. Heavy metals persist in body because they are stable, non-biodegradable and xenobiotic in nature through inhalation of air, contaminated food or eating without washing hands. Accumulation of heavy metals inside a body makes is integral part of a body. With the help of certain proteins present in kidney can detoxify. Metallothionein is a cysteine rich protein has crucial role in detoxification. It is been observed that autism patient suffers from dysfunctional metallothionein (MT) protein. There are several diseases which are the cause of exposure to heavy metal contamination like Mina-mata (Hg), Itai-Itai (Cd), dental fluorosis (Fe), skeletal deformity (Fe) etc.Parkinson’s Disease (PD) is a progressive neurodegenerative disorder consequence of high concentration of iron, neurotransmitter, dopamine.Destruction of neurons in the SubstantiaNigra Pars Compacta (SNpc) of the basal ganglia causes PD. It is been observed that dopamine is prone to auto oxidization in present of heavy metals. Factors for PD can be geographic association, industrial use of heavy metals and exposure to iron, zinc, copper, mercury, magnesium, and manganese [8].

**5.1.Insomnia:**

Insomnia is a most common disorder in millions of people and even in youngsters. Accidental inhalations of nickel carbonyl can results into acute toxic effect of insomnia. It has been reported that the increment of blood lead level can cause sleep disorder [8, 9].

**5.2.Arthritis:**

Arthritis is inflammatory disease found in joints of patients. Long-drawn-out exposure to heavy metals like iron, copper, lead, cadmium and mercury can be the causative agents of rheumatoid arthritis. High concentration of lead (Pb) consumption can affect bones and cartilages which lead to osteoarthritis (OA)[10]. Rheumatoid Arthritis can take place due to high blood cupper level as it is been observed that patients suffering from rheumatoid arthritis have high level of blood cupper than Osteoarthritis patients and normal human being [8,11].

**5.3.Autoimmune disease:**

Every human body has self defence system called immunity which protects body from hijacking the body by pathogens. But sometimes it happens that the body is unable to distinguish between self and foreign cells and attacks the healthy cells. This phenomenon is called autoimmune disorder. Heavy metals and xenobiotic compounds can have elementary role to hamper immune system. Studies reported that T cells can be stimulated by adjuvant from microbes or xenobiotic compounds like heavy metals mostly Hg and gold (Ag) [8].

**5.4. Asthma:**

One of the most common chronic health conditions which affecting millions of individuals is asthma. Association of asthma can cause childhood asthma. The elevated urinary levels of metals such as Cr, Cu, As, Se, Sr, Mo, Cd, Sn, Sb, W and U were significantly associated [8,12].

**5.5. Kidney Disease:**

Lead (Pb), mercury (Hg), and cadmium (Cd) are the common metals affecting severely renal health mostly cadmium(Cd) [13].Accumulation of Cd causes glomerular damage, leading to albuminuria and a progressive decline in Glomerular Filtration Rate (GFR), eventually can cause end stage renal failure. Studies reported that Cd exposure can cause Chronic Kidney Disease (CKD), especially in adults with hypertension or diabetes. Zinc is considered to be relatively non-toxic, especially if taken orally [8]**.**

**5.6. Hypertension:**

Mercury, cadmium, and other heavy metals play a crucial role for inactivating numerous enzymatic reactions, amino acids, and sulphur-containing antioxidants with subsequent decreased oxidant defence and increases oxidative stress. These heavy metals have high affinity for sulfhydryl groups. Mercury induces mitochondrial dysfunction with reduction in ATP, depletion of glutathione, and increased lipid peroxidation; increased oxidative stress is common. Selenium antagonizes mercury toxicity [8].

**5.7. Alzheimer’s diseases (AD):**

Another chronic neurodegenerative disease isAlzheimer’s diseases (AD) that destroys memory, thinking skills and eventually the ability to carry out normal functions of daily need and worsens over the period.Heavy metals and dioxins exhibits their toxic effects on the enzymes like superoxide dismutase, cytochrome P450 and glutathione peroxidase, responsible for cellular proliferations, growth controls and cell death.Modulation of gene expression, reduction of the activity of proteins, act on signal transduction, generation of ROS/RNS, alternation of cellular proliferations and differentiations and death, damage cells of brain, DNA damage of brain tissues can be caused by heavy metals like cobalt, cadmium, and copper thus leads to neurodegenerative diseases like Parkinson disease, Alzheimer disease, and amyotrophic lateral sclerosis [8, 14].

**5.8. Infertility:**

The World Health Organization (WHO) evaluates that 60 to 80 million couples worldwide currently suffer from infertility, varies across regions of the world and is approximated to affect 8 to 12 per cent of couples. Globally, most infertile couples suffer from primary infertility (inability to conceive within two years) . Exposure to heavy metals such as Cd, Hg, Pb, Ar, may be highly involved in impaired human fertility [15, 16]. Tobacco and smoking is the primary source of Cd and lead (Pb) intake, observed in serum and semen of infertile smokers [17]. Basal cadmium excretion was significantly higher in the infertile women compared with the pregnant women [8].

**6. Algae in Bioremediation:**

Being photosynthetic organism, fresh water living and salt water living algae can be a potential biosorbent. Immobilized cells of some algae can be efficient enough to remove heavy metals [1]. Presence of cell wall in algae has great role in bio sorption. Presence of Carboxylic, amino, hydroxyl, carbonyl,and sulfonic groups on the algal cell surface helps in metal binding. Here are few listed algae helps in bioremediation [18, 19, 20].

**Table-1: List of Algae participating to remove heavy metals**

|  |  |  |
| --- | --- | --- |
| **Algae** | **Metal Removal** | **References** |
| *Ocillatoriaangustissima* | Co, Cu, Zn | [21] |
| *Spirogyra species* | Cu(II) | [22] |
| *Spirogyra* | Cr(III) | [23] |
| *Spirogyra species* | Pb | [24] |
| *Caulerpalentillifera* | Cu, Zn, Cd, Pb | [25] |
| *Fucusspiralis* | Ni, Cu, Zn, Cd, Pb | [26] |
| *Oedogonium sp.* | Cd | [27] |
| *Laminaria japonica* | Ni, Cu, Zn, Cd | [28] |
| *Oedogoniumhatei* | Cr ,Ni | [29,30] |
| *Green algae* | Co(II), Cd(II), Pb(II) | [31] |
| *Anabaena sphaerica* | Cd(II), Pb(II) | [32] |
| *Spirulina* | Cr | [33] |
| *Spirulina platensis* | Cr | [34] |
| *Pelvetiacanaliculata* | Cu, Zn | [35] |

**7.Fungi in Bioremediation:**

There are several advantages of growing fungi, like it can be grown easily, ability to produce high biomass and at the same time it can be manipulated morphologically and genetically. Fungi are resistant to high metal accumulation. Thus it can be an effective biosorbent to remove heavy metals. Presence of functional groups like carboxyl, amine, hydroxyl, phosphate and sulfhydryl groups in the cell wall of fungi helps in metal sorption. Here are few listed of those [36,37,38,39] .

**Table-2: List of Fungi participating to remove heavy metals**

|  |  |  |
| --- | --- | --- |
| **Fungae** | **Metal Removal** | **References** |
| *Aspergillusflavus* | Cu(II), Pb(II) | [40] |
| *Lentinusedodes* | Zn, Cd, Hg | [41] |
| *Rhizopusdelemar* | Ni, Cu | [42] |
| *Aspergillusniger* | Mn, Fe, Ni, Cu, Zn, Cd, Pb | [43] |
| *Fusariumsolani* | Cr(VI) | [44] |
| *Galerinavittiformis* | Cr, Cu, Zn, Cd, Pb | [45] |
| *Zygosaccharomycesrouxii, Saccharomyces cerevisiae* | Fe, Cu, Zn, Cd | [46] |
| *Fusarium sp.* | Cr(VI) | [47] |
| *Aspergillusflavus* | Hg | [48] |
| *Botrytis cinerea* | Cu, Cd | [49] |
| *Neurosporacrassa* | Cu, Pb | [50] |
| *Aspergillus sp.* | Cr(VI) | [51] |
| *Aspergillusniger* | Cu | [52] |
| *Lactariusscrobiculatus* | Cd(II), Pb(II) | [53] |
| *Amanita rubescens* | Cd, Pb | [54] |

**8.Conclusion:**

Uncontrolled excretion of heavy metals from industry not only hampers water but also human health. Being xenobiotic compound and non-biodegradable compound it really tough to get rid of these wastes. These heavy metals can be the serious cause of human diseases. Not only genes which are controlling this diseases but also these heavy metals as an environmental parameter. It is necessary to remove heavy metal from environment. Efficient techniques need to be used to remove such wastes. Depending upon biological process heavy metals can be removed. Also several algae and fungi come to rescue. Their cell wall structure and cell surface area plays major role to remove such heavy metals. So bioremediation can be an alternative and efficient to protect environment from heavy metal pollution as well as to remove such pollutants.

**References:**

1. Ghosh, Arpita, et al. “Recent Advances in Bioremediation of Heavy Metals and Metal Complex Dyes: Review.” Journal of Environmental Engineering, vol. 142, no. 9, 2016, doi:10.1061/(asce)ee.1943-7870.0000965.
2. Leong, Yoong Kit, and Jo-Shu Chang. “Bioremediation of Heavy Metals Using Microalgae: Recent Advances and Mechanisms.” Bioresource Technology, vol. 303, 2020, p. 122886., doi:10.1016/j.biortech.2020.122886.
3. Ali, Naeem, et al. “Physicochemical Characterization and Bioremediation Perspective of Textile Effluent, Dyes and Metals by Indigenous Bacteria.” Journal of Hazardous Materials, vol. 164, no. 1, 2009, pp. 322–328., doi:10.1016/j.jhazmat.2008.08.006
4. Vidali, M. “Bioremediation. An Overview.” Pure and Applied Chemistry, vol. 73, no. 7, 2001, pp. 1163–1172., doi:10.1351/pac200173071163
5. Vidali, M. “Bioremediation. An Overview.” Pure and Applied Chemistry, vol. 73, no. 7, 2001, pp. 1163–1172., doi:10.1351/pac200173071163
6. Iwamoto, Tomotada, and Masao Nasu. “Current Bioremediation Practice and Perspective.” Journal of Bioscience and Bioengineering, vol. 92, no. 1, 2001, pp. 1–8., doi:10.1016/s1389-1723(01)80190-0.
7. Diels, L., et al. “Heavy Metals Bioremediation of Soil.” Molecular Biotechnology, vol. 12, no. 2, 1999, pp. 149–158., doi:10.1385/mb:12:2:149.
8. Morais, Simone, et al. “Heavy Metals and Human Health.” Environmental Health - Emerging Issues and Practice, 2012, doi:10.5772/29869.
9. Das, K. K., Das, S. N., &Dhundasi, S. A. (2008). Nickel, its adverse health effects & oxidative stress. The Indian journal of medical research, 128(4), 412–425
10. Nelson, Amanda E, et al. “Whole Blood Lead Levels Are Associated with Radiographic and Symptomatic Knee Osteoarthritis: a Cross-Sectional Analysis in the Johnston County Osteoarthritis Project.” Arthritis Research & Therapy, vol. 13, no. 2, 2011, doi:10.1186/ar3270.
11. Yang, Tao-Hsiang, et al. “Increased Inflammation in Rheumatoid Arthritis Patients Living Where Farm Soils Contain High Levels of Copper.” Journal of the Formosan Medical Association, vol. 115, no. 11, 2016, pp. 991–996., doi:10.1016/j.jfma.2015.10.001.
12. Huang, Xiji, et al. “Association between Concentrations of Metals in Urine and Adult Asthma: A Case-Control Study in Wuhan, China.” Plos One, vol. 11, no. 5, 2016, doi:10.1371/journal.pone.0155818.
13. Kim, Nam Hee, et al. “Environmental Heavy Metal Exposure and Chronic Kidney Disease in the General Population.” Journal of Korean Medical Science, vol. 30, no. 3, 2015, p. 272., doi:10.3346/jkms.2015.30.3.272.
14. Matés, José M., et al. “Roles of Dioxins and Heavy Metals in Cancer and Neurological Diseases Using ROS-Mediated Mechanisms.” Free Radical Biology and Medicine, vol. 49, no. 9, 2010, pp. 1328–1341., doi:10.1016/j.freeradbiomed.2010.07.028.
15. Queiroz, Erika KalteneckerRetto De, and William Waissmann. “Occupational Exposure and Effects on the Male Reproductive System.” Cadernos De SaúdePública, vol. 22, no. 3, 2006, pp. 485–493., doi:10.1590/s0102-311x2006000300003.
16. Pizent, Alica, et al. “Reproductive Toxicity of Metals in Men.” Archives of Industrial Hygiene and Toxicology, vol. 63, no. Supplement-1, 2012, doi:10.2478/10004-1254-63-2012-2151.
17. Qiao, Zhong-Dong, et al. “The Hazardous Effects of Tobacco Smoking on Male Fertility.” Asian Journal of Andrology, vol. 17, no. 6, 2015, p. 954., doi:10.4103/1008-682x.150847
18. Vilar, Vítor J. P., et al. “Modeling Equilibrium and Kinetics of Metal Uptake by Algal Biomass in Continuous Stirred and Packed Bed Adsorbers.” Adsorption, vol. 13, no. 5-6, 2007, pp. 587–601., doi:10.1007/s10450-007-9029-1.
19. Girardi, Franciélle, et al. “Marine MacroalgaePelvetiaCanaliculata (Linnaeus) as Natural Cation Exchanger for Metal Ions Separation: A Case Study on Copper and Zinc Ions Removal.” Chemical Engineering Journal, vol. 247, 2014, pp. 320–329., doi:10.1016/j.cej.2014.03.007
20. He, Jinsong, and J. Paul Chen. “A Comprehensive Review on Biosorption of Heavy Metals by Algal Biomass: Materials, Performances, Chemistry, and Modeling Simulation Tools.” Bioresource Technology, vol. 160, 2014, pp. 67–78., doi:10.1016/j.biortech.2014.01.068.
21. Mohapatra, H, and R Gupta. “Concurrent Sorption of Zn(II), Cu(II) and Co(II) by OscillatoriaAngustissima as a Function of PH in Binary and Ternary Metal Solutions.” Bioresource Technology, vol. 96, no. 12, 2005, pp. 1387–1398., doi:10.1016/j.biortech.2004.11.004.
22. Gupta, V.k., et al. “Biosorption of Copper(II) from Aqueous Solutions by Spirogyra Species.” Journal of Colloid and Interface Science, vol. 296, no. 1, 2006, pp. 59–63., doi:10.1016/j.jcis.2005.08.033.
23. Bishnoi, Narsi R., et al. “Biosorption of Cr(III) from Aqueous Solution Using Algal Biomass Spirogyra Spp.” Journal of Hazardous Materials, vol. 145, no. 1-2, 2007, pp. 142–147., doi:10.1016/j.jhazmat.2006.10.093.
24. Gupta, V.k., and A. Rastogi. “Biosorption of Lead from Aqueous Solutions by Green Algae Spirogyra Species: Kinetics and Equilibrium Studies.” Journal of Hazardous Materials, vol. 152, no. 1, 2008, pp. 407–414., doi:10.1016/j.jhazmat.2007.07.028
25. Pavasant P, E., et al. “Biosorption of Cu(II), Cd(II) Pb(II) and Zn(II) using dried marine green macroalgaCaulerpalentillifera.”Bioresource Technology, vol 97, no. 18,2006, pp. 2321-2329., doi.org/10.1016/j.biortech.2005.10.032.
26. Romera, E., et al. “Comparative Study of Biosorption of Heavy Metals Using Different Types of Algae.” Bioresource Technology, vol. 98, no. 17, 2007, pp. 3344–3353.,doi:10.1016/j.biortech.2006.09.026.
27. Gupta, V.k., and A. Rastogi. “Equilibrium and Kinetic Modelling of Cadmium(II) Biosorption by Nonliving Algal Biomass Oedogonium Sp. from Aqueous Phase.” Journal of Hazardous Materials, vol. 153, no. 1-2, 2008, pp. 759–766., doi:10.1016/j.jhazmat.2007.09.021.
28. Liu, Yinghui et al. “Biosorption of Cd2+, Cu2+, Ni2+ and Zn2+ ions from aqueous solutions by pretreated biomass of brown algae.” Journal of hazardous materials vol. 163,2-3 (2009): 931-8. doi:10.1016/j.jhazmat.2008.07.046.
29. Gupta, V.k., and A. Rastogi. “Biosorption of Hexavalent Chromium by Raw and Acid-Treated Green Alga OedogoniumHatei from Aqueous Solutions.” Journal of Hazardous Materials, vol. 163, no. 1, 2009, pp. 396–402., doi:10.1016/j.jhazmat.2008.06.104.
30. Gupta, Vinod K., et al. “Biosorption of Nickel onto Treated Alga (OedogoniumHatei): Application of Isotherm and Kinetic Models.” Journal of Colloid and Interface Science, vol. 342, no. 2, 2010, pp. 533–539., doi:10.1016/j.jcis.2009.10.074.
31. Bulgariu, Dumitru, and Laura Bulgariu. “Equilibrium and Kinetics Studies of Heavy Metal Ions Biosorption on Green Algae Waste Biomass.” Bioresource Technology, vol. 103, no. 1, 2012, pp. 489–493., doi:10.1016/j.biortech.2011.10.016.
32. Aty, Azza M. Abdel, et al. “Biosorption of Cadmium and Lead from Aqueous Solution by Fresh Water Alga Anabaena Sphaerica Biomass.” Journal of Advanced Research, vol. 4, no. 4, 2013, pp. 367–374., doi:10.1016/j.jare.2012.07.004.
33. Rezaei, Hassan. “Biosorption of Chromium by Using Spirulina Sp.” Arabian Journal of Chemistry, vol. 9, no. 6, 2016, pp. 846–853., doi:10.1016/j.arabjc.2013.11.008.
34. Al-Homaidan, Ali A., et al. “Biosorption of Copper Ions from Aqueous Solutions by Spirulina Platensis Biomass.” Arabian Journal of Chemistry, vol. 7, no. 1, 2014, pp. 57–62., doi:10.1016/j.arabjc.2013.05.022.
35. Girardi, Franciélle, et al. “Marine MacroalgaePelvetiaCanaliculata (Linnaeus) as Natural Cation Exchanger for Metal Ions Separation: A Case Study on Copper and Zinc Ions Removal.” Chemical Engineering Journal, vol. 247, 2014, pp. 320–329., doi:10.1016/j.cej.2014.03.007.
36. Akar, Tamer, and SibelTunali. “Biosorption Characteristics of AspergillusFlavus Biomass for Removal of Pb(II) and Cu(II) Ions from an Aqueous Solution.” Bioresource Technology, vol. 97, no. 15, 2006, pp. 1780–1787., doi:10.1016/j.biortech.2005.09.009.
37. Guimarães-Soares, Luís, et al. “Metal-Binding Proteins and Peptides in the Aquatic Fungi FontanosporaFusiramosa and FlagellosporaCurta Exposed to Severe Metal Stress.” Science of The Total Environment, vol. 372, no. 1, 2006, pp. 148–156., doi:10.1016/j.scitotenv.2006.09.017.
38. Sun, Fengqin, and Zongze Shao. “Biosorption and Bioaccumulation of Lead by Penicillium Sp. Psf-2 Isolated from the Deep Sea Sediment of the Pacific Ocean.” Extremophiles, vol. 11, no. 6, 2007, pp. 853–858., doi:10.1007/s00792-007-0097-7.
39. Fomina, M., et al. “Fungal Transformations of Uranium Oxides.” Environmental Microbiology, vol. 9, no. 7, 2007, pp. 1696–1710., doi:10.1111/j.1462-2920.2007.01288.x.
40. Akar, Tamer, and SibelTunali. “Biosorption Characteristics of AspergillusFlavus Biomass for Removal of Pb(II) and Cu(II) Ions from an Aqueous Solution.” Bioresource Technology, vol. 97, no. 15, 2006, pp. 1780–1787., doi:10.1016/j.biortech.2005.09.009.
41. Bayramoğlu, Gülay, and M. Yakup Arıca. “Removal of Heavy Mercury(II), Cadmium(II) and Zinc(II) Metal Ions by Live and Heat Inactivated LentinusEdodes Pellets.” Chemical Engineering Journal, vol. 143, no. 1-3, 2008, pp. 133–140., doi:10.1016/j.cej.2008.01.002.
42. Açıkel, Ünsal, and Tuğba Alp. “A Study on the Inhibition Kinetics of Bioaccumulation of Cu(II) and Ni(II) Ions Using RhizopusDelemar.” Journal of Hazardous Materials, vol. 168, no. 2-3, 2009, pp. 1449–1458., doi:10.1016/j.jhazmat.2009.03.040.
43. Tsekova, K., et al. “Removal of Heavy Metals from Industrial Wastewater by Free and Immobilized Cells of Aspergillus Niger.” International Biodeterioration& Biodegradation, vol. 64, no. 6, 2010, pp. 447–451., doi:10.1016/j.ibiod.2010.05.003.
44. M. Sen ,M. GhoshDastidar. “Biosorption of Cr [VI]by resting cells of Fusariumsolani.” Iran. J. Environ. Health Sci. vol. 8, no.2, pp. 153-158. E-ISSN: 1735-2746
45. Damodaran, Dilna, et al. “Effect of Chelaters on Bioaccumulation of Cd (II), Cu (II), Cr (VI), Pb (II) and Zn (II) in GalerinaVittiformis from Soil.” International Biodeterioration& Biodegradation, vol. 85, 2013, pp. 182–188., doi:10.1016/j.ibiod.2013.05.031.
46. Li, Chunsheng, et al. “Effect of NaCl on the Heavy Metal Tolerance and Bioaccumulation of ZygosaccharomycesRouxii and Saccharomyces Cerevisiae.” Bioresource Technology, vol. 143, 2013, pp. 46–52., doi:10.1016/j.biortech.2013.05.114.
47. Guria, Manas Kumar, et al. “A Green Chemical Approach for Biotransformation of Cr(VI) to Cr(III), Utilizing Fusarium Sp. MMT1 and Consequent Structural Alteration of Cell Morphology.” Journal of Environmental Chemical Engineering, vol. 2, no. 1, 2014, pp. 424–433., doi:10.1016/j.jece.2014.01.016.
48. Kurniati, Evi, et al. “Potential Bioremediation of Mercury-Contaminated Substrate Using Filamentous Fungi Isolated from Forest Soil.” Journal of Environmental Sciences, vol. 26, no. 6, 2014, pp. 1223–1231., doi:10.1016/s1001-0742(13)60592-6.
49. Akar, Tamer, and SibelTunali. “Biosorption Performance of Botrytis Cinerea Fungal by-Products for Removal of Cd(II) and Cu(II) Ions from Aqueous Solutions.” Minerals Engineering, vol. 18, no. 11, 2005, pp. 1099–1109., doi:10.1016/j.mineng.2005.03.002.
50. Kiran, Ismail, et al. “Biosorption of Pb(II) and Cu(II) from Aqueous Solutions by Pretreated Biomass of NeurosporaCrassa.” Process Biochemistry, vol. 40, no. 11, 2005, pp. 3550–3558., doi:10.1016/j.procbio.2005.03.051.
51. Sen, Mousumi, et al. “Biosorption of Chromium (VI) by NonlivingFusarium Sp. Isolated from Soil.” Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management, vol. 9, no. 3, 2005, pp. 147–151., doi:10.1061/(asce)1090-025x(2005)9:3(147).
52. Mukhopadhyay, M, et al. “Kinetic Modeling for the Biosorption of Copper by PretreatedAspergillus Niger Biomass.” Bioresource Technology, vol. 98, no. 9, 2007, pp. 1781–1787., doi:10.1016/j.biortech.2006.06.025.
53. Anayurt, RuhanAltun, et al. “Equilibrium, Thermodynamic and Kinetic Studies on Biosorption of Pb(II) and Cd(II) from Aqueous Solution by Macrofungus (LactariusScrobiculatus) Biomass.” Chemical Engineering Journal, vol. 151, no. 1-3, 2009, pp. 255–261., doi:10.1016/j.cej.2009.03.002.
54. Sarı, Ahmet, and Mustafa Tuzen. “Kinetic and Equilibrium Studies of Biosorption of Pb(II) and Cd(II) from Aqueous Solution by Macrofungus (Amanita Rubescens) Biomass.” Journal of Hazardous Materials, vol. 164, no. 2-3, 2009, pp. 1004–1011., doi:10.1016/j.jhazmat.2008.09.002.