International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 3 Number 7 (2014) pp. 495-504**
http://www.ijcmas.com

Review Article

E (Electronic) Waste Management using Biological systems-overview

Shuchi Patel and Avani Kasture*

C. G. Bhakta Institute of Biotechnology, Uka Tarsadia University, Maliba Campus, Bardoli Mahuva Road, Tarsadi, Dist. Surat, Gujarat, India. 394350.
**Corresponding author*

A B S T R A C T

Keywords

E (Electronic) waste, Microremediation, Phytoremediation, Vermiremediation

The constantly changing today's world of technology has lead to the serious problem of E (Electronic) waste. E-waste constitute multiple components some of which are toxic that can cause serious health and environmental issues if not handled properly. This review article provides the associated impacts and possible management of E-waste using Biological systems. Physical incineration and chemical processes using strong acids are hazardous as well as expensive for treatment, therefore biological approaches using microorganisms, earthworms and plants are valuable alternatives to traditional methods.

Introduction

The word “waste” refers to discarded material which are no longer in use and discarded by the possessor. Every day, enormous quantity of waste is generated, which is at present in need of attention (Zaved et al., 2008). The spectacular developments in modern times have undoubtedly enhanced the quality of our lives. At the same time, these have led to manifold problems, including the problem of massive amount of hazardous waste and other wastes generated from electric products called "Electronic-waste"**.** With the presence of deadly chemicals and toxic substances in the electronic gadgets, disposal of e-waste is becoming an environmental and health nightmare (Agnihotri, 2011; Saoji, 2012).

Europeans produce approximately 20 kilograms of e-waste/person/year, while U.S. residents produce about 7 kilograms of e-waste/person/year (Jennifer Namias, 2013). The total broken down and obsolete e-waste generated in India reckoned to be about 1, 46,000 tonnes yearly (Sharma et al., 2012). Therefore, it has become paramount in the world to take adequate measures to control the rise in electronic waste as they could rise by 50% in the next decade consequently increasing environmental pollution and health hazards (Martin et al., 2008; Mohammed et al., 2013).

E waste

Electronic waste is the used electronic products that require recycling or other proper forms of disposal (Mohammed et al., 2013). It consist of more than 1000 different substances, which are 'hazardous' or 'nonhazardous'. Broadly, it consists of metals like copper (Cu), aluminum (Al) and precious metals, e.g. silver (Ag), gold (Au), platinum, palladium, etc. The presence of elements like lead, mercury, arsenic, cadmium, selenium and hexavalent chromium and flame retardants beyond threshold quantities causes adverse effect on living the organisms and environment (Zaved et al., 2008; Needhidasan, 2014; Puckett et al., 2002; Sinha, 2002; Widmer et al., 2005). The disposal of e-waste is a particular problem faced in many regions across the globe and is of concern mainly due to the toxicity and carcinogenicity of some of the substances if not processed properly (Saoji., 2012).

E waste management and control

Waste management refers to all measures taken to protect human and environmental from the dangers of constituents of electronic and other wastes. It is generally undertaken to reduce their effects on health and the environment and possible to recover valuable resources from them (Ogbuene et al., 2013). Management of electronic wastes unlike non-hazardous wastes is the responsibility of the producing industries, marketers, users and government. The industries should adopt measures that will reduce, the sizes of their products and quantities of hazardous materials used in their production (UNEP, 2010).

The hazardous materials could, if possible, be replaced with non-hazardous ones. Governments on the other hand, should adopt proper regulatory policies, consider privatization of electronic waste and create public awareness (Mohammed et al., 2013).

Microremediation of E waste

Microremediation is defined as the use of the microorganisms to eliminate, contain or transform the contaminants to non-hazardous or less-hazardous form in the environment through the metabolisms of microorganisms (Mulligan et al., 2001). There are 6 major mechanisms in microremediation of toxic metals which are (1) Bioleaching; (2) Biosorption; (3) Bioaccumulation; (4) Biotransformation; (5) Biomineralization; and (6) Microbially-enhanced chemisorption of metals.

Bioleaching

Bioleaching uses a natural ability of the microorganisms to transform metals present in the waste in a solid form in a dissolved form. There are two forms of bioleaching : direct leaching and indirect leaching. Direct leaching makes use of the organic acids produced by the microbes, to oxidize the insoluble toxic metals, turning them into ions which they become soluble. In Indirect leaching metal oxidizing bacteria are used that oxidize the metal surrounding the microbe. In most cases, the anion of the target metal compounds is oxidized, giving out free metal ions in aqueous medium (Tichy et al., 1998).

Biosoprtion

Biosorption refers to the concentrating and binding of soluble contaminants to the surface of cellular structure, it does not requires active metabolism, in this case the soluble contaminants are ionized toxic metals (Volesky, and Holan, 1995).

Bioaccumulation

It is defined as the absorption of contaminants within the organism, which are transferred into a biomass cell within the cellular structure and concentrated there, this process requires active metabolism (Prakash et al., 2012). For organic contaminants, there are sometimes chemical reactions in the cell cytoplasm to convert them to other compounds; however, the metals entering the cell cytoplasm will not undergo any reaction but sequestered instead (Hou et al., 2006).

Biotransformation

Biotransformation refers to the process in which a substance is changed from one chemical form to another chemical form by chemical reactions; in the case of toxic metals, the oxidation state is changed by the addition or removal of electrons, thus their chemical properties are also changed (Prakash et al., 2012).

There are 2 ways for biotransformation process. Direct enzymatic reduction, in which multivalent toxic metal ions are reduced by accepting electrons from the enzymes in the exterior of the cell. Indirect reduction, can be used to reduce and immobilize multivalent toxic metal ions in sedimentary and subsurface environment by actions of metal-reducing or sulfate reducing bacteria (Tabak et al., 2005).

Biomineralization

Biomineralization describes the process in which toxic metal ions combine with anions or ligands produced from the microbes to form precipitation (Ronald and Don, 2005).

Microbially-enhanced chemisorption of metals

Chemisorption is similar to adsorption except there is a chemical reaction between the surface and the adsorbate (Volesky and Holan, 1995). In microbially-enhanced chemisorption of metals a series of chemical reactions in which microbes first precipitate a bio-mineral of a non-target metal known as priming deposits, the priming deposits, then act as a nucleation focus for the subsequent deposition of the target metal (Tabak et al., 2005).

Phytoremediation for Electronic Waste

The act of removing toxic metals from the environment by the use of metal accumulating plants is termed phytoremediation (Vinita, 2007). There are four basic methods employed in remediation using plants 1) Phytoextraction, 2) Phytovolatilization, 3) Phytostablization and 4) Rhizofilteration (Mohammed et al., 2013).

Phytoextraction

Phytoextraction refers to the uptake of toxic metals from the soil or polluted water by plant roots and translocating and accumulating them in plant tissues. After the metals are mobilized, and captured by root cells, they bind to the cell wall, followed by slow diffusion through different cell walls and enter the xylem to transport to other parts of the plant (Lasat, 2002). The plants are later harvested and destroyed by burning in landfills or the metals could be recycled by a process called phytomining (Vinita, 2007).

Phytovolatilization

Phytovolatilization is the act of transpiration of organic and inorganic metals and evaporation of the metals to the atmosphere through the stem and leaves of plants. This method is much more effective for organic metals, but can be used for few inorganic metals (Le Duc*et* et al., 2004).

Dealing with E waste

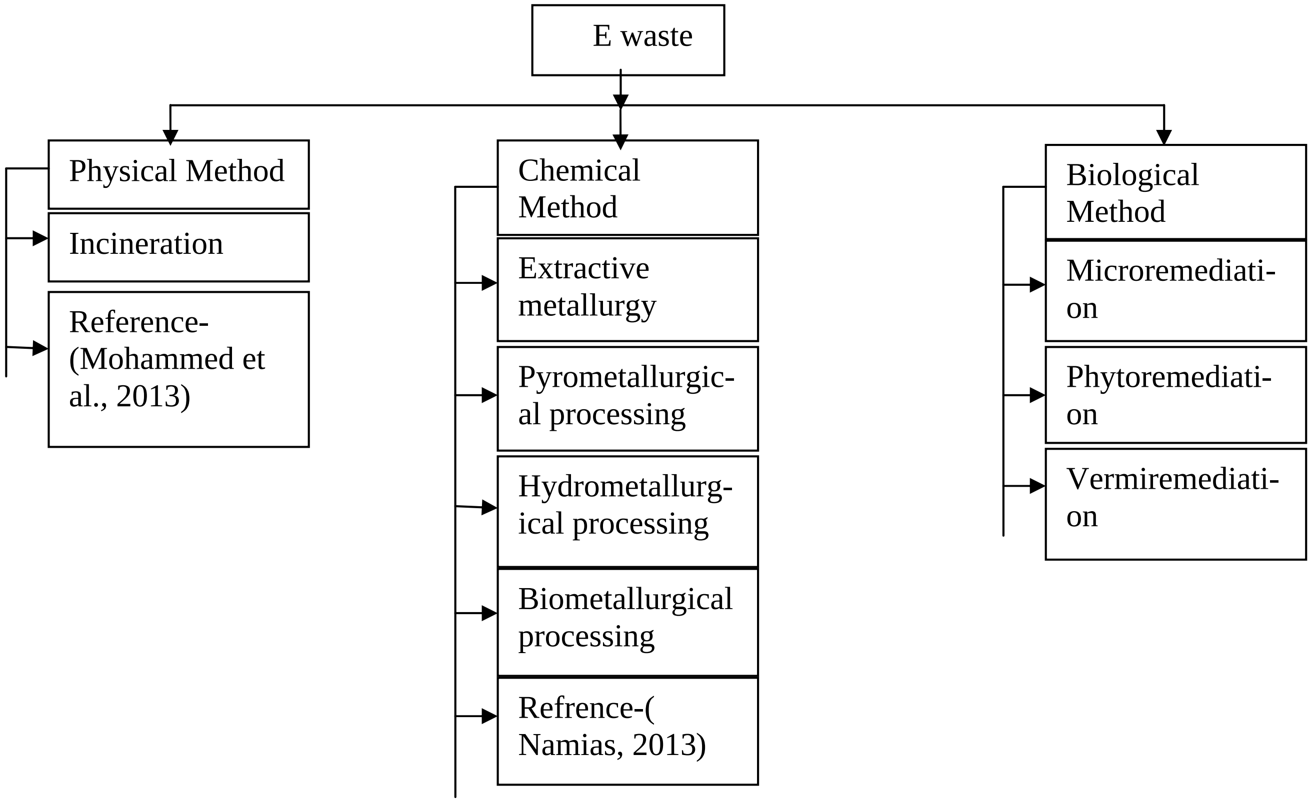

Table.1 Some microorganisms identified for bioleaching of toxic metals

The organism used	Type	Name of toxic metals removed
Acidithiobacillus thioxidans	Bacteria	Arsenic, Lead
Micrococcus roseus	Bacteria	Cadmium
Thiobacillus ferrooxidans	Bacteria	Arsenic, Lead
Aspergillus fumigatus	Fungus	Arsenic
Aspergillus niger	Fungus	Cadmium, Lead

(Source: Stephen & Macnaughtont, 1999; Ren et al., 2009)

Table.2 Some microorganisms identified for biosorption of toxic metals

The organism used	Type	Name of toxic metals removed
Bacillus sphaericus	Bacteria	Chromium
Myxococcus xanthus	Bacteria	Uranium
Pseudomonas aeruginosa	Bacteria	Cadmium, Uranium
Streptoverticillium cinnamoneum	Bacteria	Lead
Rhizopus arrhizus	Fungus	Uranium
Saccharomyces cerevisiae	Fungus	Cadmium

(Source: Hu et al., 1996; Atkinson et al., 1998; Ahalya et al., 2003)

Table.3 Some microorganisms identified for bioaccumulation of toxic metals

The organism used	Type	Name of toxic metals removed
Bacillus circulans	Bacteria	Chromium
Bacillus megaterium	Bacteria	Chromium
Deinococcus radiodurans	Bacteria	Uranium
Micrococcus luteus	Bacteria	Uranium
Aspergillus niger	Fungus	Chromium, Lead
Monodictys pelagica	Fungus	Chromium, Lead

(Source: Demirbaş, 2001; Srinath et al., 2002; Malik, 2004; Juwarkar and Yadav, 2010)

Table.4 Some microorganisms identified for biotransformation of toxic metals

The organism used	Type	Name of toxic metals removed
Anaeromyxobacter sp.	Bacteria	Uranium
Clostridium sphenoides	Bacteria	Uranium
Halomonas sp.	Bacteria	Uranium
Serratia sp.	Bacteria	Chromium
Fusarium oxysporum	Fungus	Cadmium
Rhizopus oryzae	Fungus	Chromium

(Source: Lovley and Coates, 1997; Francis, 1998; Malik, 2004)

Table.5 Some microorganisms identified for biomineralization of toxic metals

The organism used	Type	Name of toxic metals removed
Bacillus fusiformis	Bacteria	Lead
Cupriavidus metallidurans	Bacteria	Cadmium
Desulfotomaculum auripigmentum	Bacteria	Arsenic
Sporosarcina ginsengisoli	Bacteria	Arsenic
Aspergillus flavus	Fungus	Lead

(Source: Tabak et al., 2005; Benzerara et al., 2011; Achal et al., 2012; Govarthanan et Al., 2012)

Table.6 Some plant species for phytoextraction of toxic metals

Plant species	Name of toxic metals removed
Alpine pennygrass (*Thlaspi caerulescens*)	Cadmium, Strontium
Amaranthus (*Amaranthus retroflexus*)	Arsenic, Strontium
Chenopodium (*Chenopodium album)*	Cadmium, Lead
Indian mustard (*Brassica juncea*)	Cadmium, Chromium
Sunflower (*Helianthus annuus*)	Arsenic, Lead

(Source: Lasat, 2002; McGrath, 2006; Rajiv et al., 2009)

Table.7 Some plant species for phytovolatilization of toxic metals

Plant species	**Name of toxic metals removed**
Cultivated tobacco (*Nicotiana tabacum*)	Mercury
Mouse-ear cress (*Arabidopsis thaliana*)	Mercury
Spring wheat (*Triticum aestivum*)	Mercury
Water hyssop (*Bacopa monnieri)*	Mercury
White clover (*Trifolium repens L.*)	Mercury
Chinese brake (*Pteris vittata*)	Arsenic
Swamp lily (*Crinum americanum*)	Selenium

(Source: Banuelos et al., 2002; Liu et al., 2007; Rajiv et al., 2009)

Table.8 Some plant species for phytostabilization of toxic metals

Plant species	**Name of toxic metals removed**
Black alder (*Alnus glutinosa*)	Uranium
Hybrid poplar (*Populus canadensis*)	Cadmium, Lead
Qaulibush (*Atriplex lentiformis*)	Uranium
Vetiver grass (*Chrysopogon zizanioides*)	Arsenic, Lead
White lupin (*Mediterranean L. albus*)	Arsenic, Cadmium
White poplar (*Populus alba*)	Cadmium, Lead

(Source: David et al., 1997; Wilde et al., 2005; John, 2007)

Table.9 Some plant species for rhizofiltration of toxic metals

Plant species	**Name of toxic metals removed**
Water hyacinth (*Eichornia crassipes*)	Arsenic
Lesser duckweed (*Lemna minor*)	Arsenic
Yellow burr head (*Limnocharis flava*)	Cadmium
Lucerne (*Medicago sativa*)	Cadmium, Lead
Chinese brake (*Pteris vittata*)	Arsenic

(Source: Natarajan, 2008; Abhilash et al., 2009; Olguín and Sánchez-Galván, 2012)

Table.10 Some earthworm species identified for removing toxic metals

Earthworm species	**Name of toxic metals removed**
Canadian worm (*Aporrectodea tuberculata*)	Cadmium, Lead
Brandling worm (*Eisenia fetida*)	Cadmium, Mercury
Lob worm (*Lumbricus terrestris*)	Cadmium, Chromium, Lead
Dendrobaena rubida	Arsenic, Lead
Eiseniella tetraedra	Chromium, Lead

(Source: John, 2007; Rajiv et al., 2009; Sinha et al., 2010; Pattnaik and Reddy, 2012)

Phytostabilization

Phytostabilization refers to the stabilizing process for contaminated soils by immobilizing toxic metals using plants so their availability to the environment is reduced (Rajiv et al., 2009). It is achieved by absorption and accumulation by the roots, adsorption onto roots, or precipitation within the root zone of plants (BNL, 2002).

Rhizofiltration

Rhizofiltration, refers to the use of plant root to absorb, adsorb, or precipitate toxic metal contaminants from aqueous medium (Anawar et al., 2008). For absorption, toxic metals are absorbed to the root surface by the actions of chemisorption, ion exchange, and complexation (Mulligan et al., 2001; Lasat, 2002; Hester et al., 2007). For adsorption, some toxic metals adsorb to the surface of the plant root (Sanchez-Galván and Olguín, 2009). For precipitation, some plants release negative charged ions which combine with some toxic metal species to form precipitants on their surface while some plants alter the pH near their root systems to allow enough hydroxide ions for toxic metal hydroxides to precipitate on their root surfaces, immobilizing their movement in water bodies thus reducing their concentration (Anawar et al., 2008).

Vermiremediation Technology

Earthworms have been reported to bio-accumulate chemical contaminants in their tissues and either biodegrade or bio-transform them into harmless products with the aid of enzymes (Sinha et al., 2010). Hartenstein et al (1980), studied that earthworms can bio-accumulate high concentrations of heavy metals like cadmium (Cd), mercury (Hg), lead (Pb) copper (Cu), manganese (Mn), calcium (Ca), iron (Fe) and zinc (Zn) in their tissues.

Acknowledgement

We wish to thank our Uka Tarsadia University and Department C. G. Bhakta Institute of Biotechnology for providing the necessary facilities for the study.

References

Abhilash, P. C., Pandey, V. C., Srivastava, P., Rakesh, P. S., Chandran, S., Singh, N., and Thomas, A. P. 2009. Phytofiltration of cadmium from water by *Limnocharis flava* and *Buchenau* grown in free-floating culture system. Journal of Hazardous Materials. 170(2): 791-797.

Achal, V., Pan, X., Fu, Q., and Zhang, D. 2012. Biomineralization based remediation of As (III) contaminated soil by *Sporosarcina ginsengisoli*. *Journal* of Hazardous materials. 201, 178-184.

Ahalya, N., Ramachandra, T. V., and Kanamadi, R. D. 2003. Biosorption of heavy metals. Res. J. Chem. Environ. 7(4), 71-79.

Ajeet, saoji., 2012. E waste management: An emerging environmental and health issue of medicak research. National journal of medical research.Volume 2.

Anawar, H. M., Garcia-Sanchez, A., Kul Alam, M. T., and Rahman, M. M. 2008. Phytofiltration of water polluted with arsenic and heavy metals. International Journal of Environment and Pollution. 33(2): 292-312.

Atkinson, B. W., Bux, F., and Kasan, H. C. 1998. Considerations for application of biosorption technology to remediate metal-contaminated industrial effluents. Water S. A. 24(2): 129-135.

Banuelos, G. S., Lin, Z. Q., Wu, L., and Terry, N. 2002. Phytoremediation of selenium-contaminated soils and waters: fundamentals and future prospects. Reviews on Environmental Health. 17(4): 291-306.

Benzerara, K., Miot, J., Morin, G., Ona-Nguema, G., Skouri-Panet, F., and Férard, C. 2011. Significance, mechanisms and environmental implications of microbial biomineralization. Comptes Rendus Geoscience. 343(2): 160-167.

BNL (Brookhaven National Laboratory). 2002. Remedial alternatives: Phytostabilization. Available at http://www.bnl.gov/erd/Peconic/Factsheet/Phytostab.pdf Accessed 17th April, 2013.

David, E.S., Ilya R., and Robert D. S. 1997. Phytoremediation of metals: using plants to remove pollutants from the environment. Current Opinion in Biotechnology. 8, 221–226.

Demirbaş, A. 2001. Heavy metal bioaccumulation by mushrooms from artificially fortified soils. Food Chemistry. 74(3): 293-301.

Agnihotri, V.K**.** 2011: "E waste in India".

Francis, A. J. 1998. Biotransformation of uranium and other actinides in radioactive wastes. Journal of Alloys and Compounds. 271, 78-84.

GZA GeoEnvironmental. 1998. www.gzea.com/bioremediation/ bioremediation.asp.

Govarthanan, M., Lee, K. J., Cho, M., Kim, J. S., Kamala-Kannan, S., and Oh, B. T. 2012. Significance of autochthonous *Bacillus sp*. *KK1* on biomineralization of lead in mine tailings. Chemosphere. 90(8): 2267-2272.

Hartenstein, R., Neuhauser, E.F. and Collier, J. 1980. Accumulation of heavy metals in the earthworm *E. foetida*. Environmental Quality. Vol. 9; pp. 23-26.

Hester, R. E., Harrison, R. M., and Wood, P. 2007. Remediation methods for contaminated sites.

John, P. 2007. Fundamentals of Site Remediation: For Metal- and Hydrocarbon-Contaminated Soils. Government Institutes, United States of America.

Hou, B., Zhu, K., Lu, J., and Zhao, Y. F. 2006. Research on bioremediation of petroleum contaminated soils and its perspectives. Sichuan Environment. 6(24): 131-140.

Hu, M. Z. C., Norman, J. M., Faison, B. D., and Reeves, M. E. 1996. Biosorption of uranium by Pseudomonas aeruginosa strain CSU: characterization and comparison studies. Biotechnology and Bioengineering. 51(2): 237-247.

Jennifer, N., 2013. The future of electronic waste recycling in the united states.

Juwarkar, A. A., and Yadav, S. K. 2010. Bioaccumulation and Biotransformation of Heavy Metals. In Bioremediation Technology. Springer.

Lasat, M. M. 2002. Phytoextraction of toxic metals. Journal of Environmental Quality. 31(1): 109-120.

Liu, P., Qiu, G. L., and Shang, L. H. 2007. Phytoremediation of mercury contaminated soil: A review [J]. Chinese Journal of Ecology. 6, 27.

Lovley, D. R., and Coates, J. D. 1997. Bioremediation of metal contamination. Current Opinion in Biotechnology. 8(3): 285-289.

Malik, A. 2004. Metal bioremediation through growing cells. Environment International. 30(2): 261-278.

Martin, E., DuanHuabo, Li Jinhui., OshaniPerera, Jason, P., Wanhua, Y. 2008. Sustainable Electronics and electrical Equipment for China and the World, a commodity chain sustainability analysis of key Chinese EEE Product chains.International Institute for Sustainable Development. Canada.Pp I---II.

McGrath, S. P., and Zhao, F. J. 2003. Phytoextraction of metals and metalloids from contaminated soils. Current Opinion in Biotechnology 14(3): 277-282.

Mohammed, A., Oyeleke, S.B., Ndamitso, M.M., Achife, C.E., and Badeggi, U.M. 2013. The Impact of Electronic Waste Disposal and Possible Microbial and Plant Control. The International Journal Of Engineering And Science (IJES) .2, 2319 – 1805.

Mulligan, C. N., Yong, R. N., and Gibbs, B. F. 2001. Remediation technologies for metal-contaminated soils and groundwater: an evaluation. Engineering Geology. 60(1): 193-207.

Natarajan, S., Stamps, R. H., Saha, U. K., and Ma, L. Q. 2008. Phytofiltration of arsenic-contaminated groundwater using Pteris vittata L.: effect of plant density and nitrogen and phosphorus levels. International Journal of Phytoremediation. 10(3): 222-235.

Ogbuene, E. B., Igwebuike, E. H. and Agusiegbe, U. M. 2013. The Impact of Open Solid Waste Dump Sites on Soil Quality: A Case Study of UgwuajiIn Enugu, British Journal of Advance Academic Research. 2 (1):43 – 53.

Olguín, E. J., and Sánchez-Galván, G. 2012. Heavy metal removal in phytofiltration and phycoremediation: the need to differentiate between bioadsorption and bioaccumulation. New Biotechnology. 30(1): 3-8.

Pattnaik, S., and Reddy, M. V. 2012. Remediation of heavy metals from urban waste by vermicomposting using earthworms: Eudrilus eugeniae, Eisenia fetida and Perionyx excavatus. International Journal of Environment and Waste Management. 10(2): 284-296.

Prakash, A., Satyanarayana, T., and Johri, B. N. 2012. Microorganisms in Environmental Management: Microbes and Environment. Dordrecht: Springer, New York, United States of America.

Pucket, J., Byster, L., and Westervelt, S. 2002. Exporting Harm: The high-tech trashing of asia, the basal action network(BAN) and silicon valley toxic coalition(SVTC).

Rajiv, K.S., Dalsukh, V., Shanu, S., Shweta, S., and Sunil, H. (2009). Bioremediation of Contaminated Sites: A low-cost nature's Biotechnology for Environmental Clean Up by Versatile Microbes, Plants & Earthworms. Nova Science Publishers. United States of America.

Sánchez-Galván, G., and Olguín, E. J. 2009. A holistic approach to phytofiltration of heavy metals: recent advances in rhizofiltration, constructed wetlands, lagoons, and bioadsorbent-based systems. Handbook of Advanced Industrial and Hazardous Wastes Treatment. 389-408.

Santhanam, N., Melvin, S., and Ramalingam, C. 2014. Electronic waste – an emerging threat to the environment of urban India. Journal of Environmental Health Science & Engineering. 12:36.

Sharma, P., Fulekar, M.H., and Pathak, B. 2012. E-Waste- A Challenge for Tomorrow. Research Journal of Recent Sciences. (3): 86-93.

Sinha, R.K., Herat, S., and Valani, D. 2010. Earthworms - The Environmental Engineers: Review of Vermiculture Technologies for Environmental Management and Resource Development. Int. J. of Environmental Engineering.

Sinha, R. K., Agarwal, S., Chauhan, K., Chandran, V., and Soni, B. K. 2010. Vermiculture Technology: Reviving the dreams of Sir Charles Darwin for scientific use of earthworms in sustainable development programs. Technology and Investment. 1(3): 155-172.

Srinath, T., Verma, T., Ramteke, P. W., and Garg, S. K. 2002. Chromium (VI) biosorption and bioaccumulation by chromate resistant bacteria. Chemosphere. 48(4): 427-435.

Stephen, J. R., and Macnaughtont, S. J. 1999. Developments in terrestrial bacterial remediation of metals. Current Opinion in Biotechnology. 10(3): 230-233.

Tabak, H. H., Lens, P., van Hullebusch, E. D., and Dejonghe, W. 2005.Developments in bioremediation of soils and sediments polluted with metals and radionuclides–1. Microbial processes and mechanisms affecting bioremediation of metal contamination and influencing metal toxicity and transport. Reviews in Environmental Science and Bio/Technology. 4(3): 115-156.

Tichy, R., Rulkens, W. H., Grotenhuis, J. T. C., Nydl, V., Cuypers, C., and Fajtl, J. 1998. Bioleaching of metals from soils or sediments. Water Science and Technology. 37(8): 119-127.

Vinita, H. 2007. Phytoremediation of toxic metal from soil and water. Journal of Environmental Biology. 28 (2): 367 – 376.

Volesky, B., and Holan, Z. R. 1995. Biosorption of heavy metals. Biotechnology Progress. 11(3): 235-250.

Wilde, E. W., Brigmon, R. L., Dunn, D. L., Heitkamp, M. A., and Dagnan, D. C. 2005. Phytoextraction of lead from firing range soil by Vetiver grass. Chemosphere. 61(10): 1451-1457.

Zaved, H. k., Mizanur M. R., Mashiar, M. R., Atiqur, R., S.M.Y. Arafat, and M. Safiur, M. R. 2008. Isolation and characterizaton of effective bacteria for solid waste degradation for organic manure. KMITL Sci. Tech. J. 8(2): 44-55.