ISSN: 0974-2115
www.jchps.com Journal of Chemical and Pharmaceutical Sciences

Toxic metal removal by *Eichhornia crassipes*

D. Sivakumar*, Manish Kumar Mandal
Department of Civil Engineering, Vel Tech High Tech Dr.Rangarajan Dr.Sakunthala Engineering College, Avadi, Chennai, Tamil Nadu, India
Corresponding Author:E.Mail:shri.sivakumar1974@gmail.com

ABSTRACT

This study was focused on removal of copper (Cu) and nickel (Ni) from electroplating industry effluent using *Eichhornia crassipes*. The experimental investigations have been carried out by using *Eichhorniacrassipes* for conducted the absorption study with various nutrient dosage (10, 20, 30, 40, 50, 60 and 70 g), dilution ratio (2, 4, 6, 8, 10, 12 and 14) and pH (3, 4, 5, 6, 7, 8 and 9).The maximumremoval percentage of copper (84.6 %) and nickel (86.3 %) from electroplating industry effluentwas obtained at optimumnutrient dosage of 60 g, dilution ratio of 10 and pH of 8. Also, the study focused on uptake of Cu and Ni from electroplating industry effluent by *Eichhornia crassipes*through bioaccumulation factor and translocation factor. The results bioaccumulation factor revealed that Ni uptake by the *Eichhornia crassipes*is higher than the Cu uptake. The results of translocation factor revealed that the root of *Eichhornia crassipes* translocate Cu and Ni to shoot of *Eichhornia crassipes*. Further, the results of experiments were validated by conducting the same experimentsin an aqueous solution.Thus, this study concluded that *Eichhornia crassipes* was effectively used as phytoextraction of Cu and Ni not only from electroplating industry effluent but also for various types of toxic metal contaminated effluent.

Keywords: Digital UV Spectrophotometer, Bioremediation, Electroplating Industry Effluent, Magnetic Stirrer.

INTRODUCTION

Among the various sources of surface water and groundwater contamination, the electroplating industry stands out as one of the most important, because it generates a considerable volume of effluent containing high concentrations of metal ions and, often, high concentrations of organic matter. Effluent generated from electroplating industry generally contains much higher concentrations of properties like total dissolved solids, suspended solids, phenols, chromium, chlorides, ammonia, and toxic metals, which must be controlled to an acceptable level before being discharged to the environment according to environmental regulations worldwide, otherwise effluent from not only from electroplating industries, other industries affect the surface water, groundwater (Sivakumar and Swaminathan, 2008) and soil environment (Sivakumar, 2011). Several treatment processes have been suggested for the removal of toxic metals from aqueous waste streams: adsorption (Sivakumar, 2012; Sivakumar, 2014a, b; Sivakumar et al., 2014b, c; Shankar, et al., 2014a), bioremediation (Sivakumar et al., 2014a; Shankar, et al., 2014b), phytoremediation (Fischerova, et al., 2005; Erakhrumen and Agbontalor, 2007), ion exchange, chemical precipitation, electro-chemical methods, electro-deionization, electro-dialysis (Sivakumar, et al., 2014e) and electro-coagulation. In recent years, considerable attention has been focused on absorption process using aquatic plants because, it has more advances than over conventional treatment methods include: low cost; high efficiency; minimization of chemical and biological sludge. This can be achieved by using constructed wetland (Türker, et al., 2014; Sivakumar, et al., 2014d). Constructed wetlands are artificial effluent treatment systems consisting of shallow ponds or channels which have been planted with aquatic plants (Ingole and Bhole, 2003 and which rely upon natural microbial, biological, physical and chemical process to treat effluent. The treatment systems of constructed wetlands are based on ecological systems found in natural wetlands. For the design and construction of treatment wetlands and the processes by which constructed wetlands can remove pollutants, it is important to have a basic understanding of how natural wetlands work. Thus, this study was conducted to remove the copper (Cu) and nickel (Ni) from electroplating industry effluent using constructed wetlands by aquatic macrophytes *Eichhornia crassipes*. The uptake capacity of *Eichhornia crassipes* was determined through bioaccumulation and translocation factors (Zacchini, et al., 2008). Further, the results of experiments were validated by conducting the same experiments in an aqueous solution for the removal and uptake capacity of Cu and Ni by *Eichhornia crassipes.*

MATERIALSAND METHODS

Collection of *Eichhornia crassipes*: The aquatic macrophytes *Eichhornia crassipes* were collected from the Porur Lake, Chennai, which had no connection with any tannery industry effluent discharge points. The collected aquatic plants were washed with distilled water and weighed. Further, the aquatic macrophytes were initially subject to stabilization in small plastic tanks containing well water and the same were preserved for 15 days period. In addition, these plastic tanks were filled with gravel and wetland soil (collected from the Porur Lake) up to five inches in height and maintained at normal temperature.

Collection of Effluent Sample: For the present study, the effluent sample was collected from electroplating industry, Ambatore Industrial Estate, Chennai with the help of air tight sterilized bottles. Samples were taken to the Environmental Engineering Laboratory for analyzing the Cu and Ni from the electroplating industry effluent. The analysis was carried out for Cu and Ni in the electroplating industry effluent using Perkin Elmer UV/Vis Spectrophotometer with the wavelength of 291 nm and 401 nm respectively. The initial concentration of Cu and Ni from electroplating industry effluent is 163 mg/l and 122 mg/l respectively.

Absorption Experiments: For the experiments, the *Eichhornia crassipes*, which maintained in the plastic tanks were collected, cleaned and introduced in the experimental tanks (constructed wetland). The experimental tanks also a plastic tank as similar to plastic tank for preserving the *Eichhornia crassipes*. Approximately, 100 g of *Eichhornia crassipes* were used in each experimental tank for this study. These experimental tanks were filled with electroplating industry effluent of 1000 ml. Triplicate of each experimental setup was maintained. In order to reduce the Cu and Ni in a electroplating industry effluent, the experimental setup (constructed wetland) was examined for a period of 7 days by 1 day interval by using aquatic macrophytes *Eichhornia crassipes* and conducted the biosorption study with various nutrient dosage (10, 20, 30, 40, 50, 60 and 70 g), dilution ratio (2, 4, 6, 8, 10, 12 and 14) and pH (3, 4, 5, 6, 7, 8 and 9). The nutrient used in this study was activated sludge which was collected from the municipal effluent treatment plant, Chennai. The dilution ratio was used such that 1 part of effluent with various numbers of part of well water, thus, the ratio of 2, 4, 6, 8, 10, 12 and 14 represents these parts of well water mixed with raw effluent. The pH was adjusted by using 0.1 M of NaOH and 0.1 M of HCl. The concentrations of the various parameters in an electroplating industry effluent before and after treatment with *Eichhornia crassipes* were determined as per the standard procedure stipulated by APHA, AWWA, WEF, 2005. The percent removals of various parameters by *Eichhornia crassipes* were calculated by using the following formula:

$$\text{Percenrage Reduction} = \frac{(C_1 - C_2)}{C_1} \text{x} 100 \qquad (1)$$

in which C_1 is concentration of the parameter before treatment with *Eichhornia crassipes* and C_2 is concentration of the parameter after treatment with *Eichhornia crassipes*.

Bioaccumulation Factor (BAF): In order to validate the above experiments, bioaccumulation and translocation factors are used. The bioaccumulation factor (BAF) is defined as the ratio of metal concentrations in the roots to those in the soil or water, and is determined using Eq. (2)

$$BAF = P_{plant} / P_{water} \qquad (2)$$

where P_{plant} is the parameters concentration in plants and P_{water} is the parameters concentration in water. If BAF > 1 indicates that the plant is accumulator.

The Translocation Factor (TF): It is defined as the ratio of metal concentration in the shoots to those in the roots

$$TF = P_{shoot} / P_{root} \qquad (3)$$

where P_{shoot} is the parameters concentration in shoot of the plant to the P_{root} is the parameters concentration in root of the plant. If TF > 1indicates that the plant translocates metals effectively from the roots to the shoots.

RESULTS AND DISCUSSIONS

The different process parameters like dilution ratio, pH and nutrient dosage were selected for conducting the biosorption study using *Eichhornia crassipes*, to reduce Cu and Ni in an electroplating industry effluent.

Effect of Dilution Ratio: Fig.1 indicates the experimental investigations conducted by changing the dilution ratio from 2 to 14 (effluent 1 : well water 2) with an increment of 2 using *Eichhornia crassipes* and for the different contact time from 1 day to 7 day with an increment of 1 day. The percentage reduction of Cu and Ni in an electroplating industry effluent using *Eichhornia crassipes* against dilution ratio (Since, day 6 is the optimum contact time found from the study, the results obtained on the day 6 was presented and the results obtained by the day 1, 2, 3, 4, 5, and 7 were not presented in this study) with a contact time of 6 days, nutrient dosage of 10 g and pH of 7 was presented in Fig.1.

The results revealed that the percentage removal for Cu and Ni in an electroplating industry effluent is low at the beginning and then increases with dilution ratio. This is because, diluted concentration of Cu and Ni in an electroplating industry effluent were sorbed easily by the *Eichhornia crassipes* than high concentration electroplating industry effluent. In other words, the active sites in the *Eichhornia crassipes* could not be effectively utilized by Cu and Ni at the beginning and thereafter absorbent sites of *Eichhornia crassipes* could be effectively utilized in later stages. Up to dilution ratio of 10, the absorption of Cu and Ni in an electroplating industry effluent by *Eichhornia crassipes* increased steadily and for the dilution ratio 12 and 14, the percentage removal results showed the resembles of the results obtained for the dilution ratio 10. Hence, the optimum dilution ratio found in this study for the maximum removal of Cu and Ni in an electroplating industry effluent is 10.

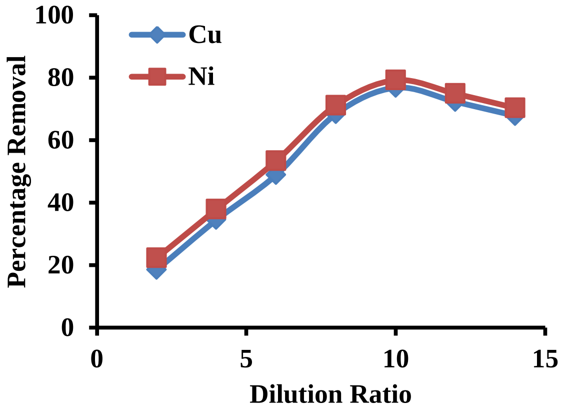

Fig.1 Removal Cu and Ni in an Electroplating Industry Effluent by*Eichhornia crassipes* against Dilution Ratio

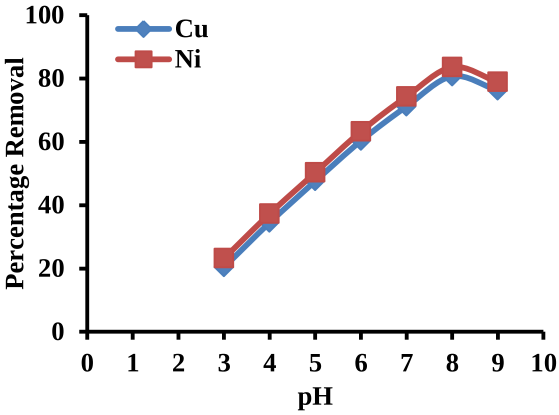

Fig.2 Removal of Cu and Ni in an Electroplating Industry Effluent by *Eichhornia crassipes* against pH

The absorption of Cu and Ni in an electroplating industry effluent on day 7 and for the dilution ratio 12 and 14, the removal percentage of Cu and Ni was not significant even the contact time and dilution ratio were higher, it is more likely that an even sufficient contact time available, significant portion of the available active sites remain undiscovered, leading to lower specific uptake for the dilution ratio 12 and 14 and for the contact time of 7 days. Thus, the maximum absorption removal percentage of Cu and Ni in an electroplating industry effluent by *Eichhornia crassipes* against dilution ratio of 10 was found to be 76.8 and 79.2 % respectively (Fig.1).

The maximum mass removal of Cu and Ni in an electroplating industry effluent per unit Kg biomass of *Eichhornia crassipes* is 1251.84 and 966.24 mg/Kg respectively against the optimum dilution ratio of 10. The bioaccumulation factor of *Eichhornia crassipes* for removing Cu and Ni in an electroplating industry effluent was 33.10 and 38.08 respectively. Similarly the translocation factor of *Eichhornia crassipes* for removing Cu and Ni in an electroplating industry effluent was 1.183 and 1.652 respectively. It is to be noted that bioaccumulation and translocation were higher for Ni than Cu indicates that Ni uptake by *Eichhornia crassipes* was higher than Cu uptake by *Eichhornia crassipes*.

Effect of pH: Fig.2 represents the experimental investigations conducted by changing the pH from 3 to 9 with an increment of 1 using *Eichhornia crassipes* and for the different contact time from 1 to 7 days with an increment of 1 day. The percentage reduction of Cu and Ni in an electroplating industry effluentusing *Eichhornia crassipes* against pH (Since, day 6 is the optimum contact time found from the study, the results obtained on the day 6 was presented and the results obtained by the day 1, 2, 3, 4, 5, and 7 were not presented in this study) with a contact time of 6 days, nutrient dosage of 10 g and an optimum dilution ratio of 10 was presented in Fig.2.

The results revealed that the percentage removal of Cu and Ni in an electroplating industry effluent is low at the beginning and then high with pH increases. This is because, in a slight alkaline to alkaline condition, the active sites in the *Eichhornia crassipes* could be effectively utilized for removing Cu and Ni in an electroplating industry effluent than in acidic condition. Up to pH of 8, the absorption of Cu and Ni in an electroplating industry effluentby *Eichhornia crassipes* increased steadily and for the pH 9, the percentage removal results showed the resembles of the results obtained for the pH 8. Hence, the optimum pH found in this study for the maximum removal of Cu and Ni in an electroplating industry effluent is 8.

The absorption of Cu and Ni in an electroplating industry effluenton day 7 and for the pH 9, the removal percentage of Cu and Ni in an electroplating industry effluentwas not significant even the contact time and pH were higher, it is more likely that an even sufficient contact time available, significant portion of the available active sites remain undiscovered, leading to lower specific uptake for the pH of 9 and for the contact time of 7 days. Thus, the maximum absorption removal percentage of Cu and Ni in an electroplating industry effluentby *Eichhornia crassipes* against the optimum pH of 8 was found to be 80.7 and 83.6 % respectively (Fig.2).

The maximum mass removal of Cu and Ni in an electroplating industry effluent per unit Kg biomass of *Eichhornia crassipes* is 1315.41 and 1019.92 mg/Kg respectively against the optimum pH of 8. The bioaccumulation factor of *Eichhornia crassipes* for removing Cu and Ni in an electroplating industry effluent was 41.81 and 50.97 respectively. Similarly, the translocation factor of *Eichhornia crassipes* for removing Cu and Ni in an electroplating industry effluent was found to be 1.415 and 2.076 respectively. As similar to dilution ratio, bioaccumulation and translocation were higher for Ni than Cu indicates that Ni uptake by *Eichhornia crassipes* was higher than Cu uptake by *Eichhornia crassipes*.

Effect of Nutrient Dosage: Fig.3 indicates the experimental investigations conducted by changing the nutrient dosage from 10 g to 70 g with an increment of 10 g using *Eichhornia crassipes* and for the different contact time from 1 day to 7 day with an increment of 1 day against the optimum dilution ratio of 10 and pH of 7. The percentage reduction of Cu and Ni in an electroplating industry effluent using *Eichhornia crassipes* against nutrient dosage (Since, day 6 is the optimum contact time found from the study, the results obtained on the day 6 was presented and the results obtained by the day 1, 2, 3, 4, 5, and 7 were not presented in this study) with a contact time of 6 days, optimum dilution ratio of 10 and an optimum pH of 8.

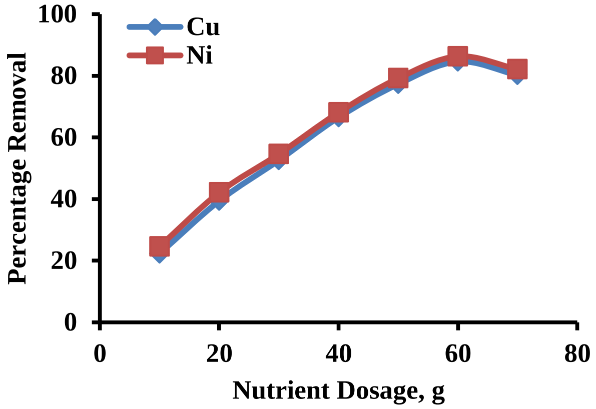

Fig.3 Removal Cu and Ni in an Electroplating Industry Effluent by *Eichhornia crassipes* against Nutrient Dosage

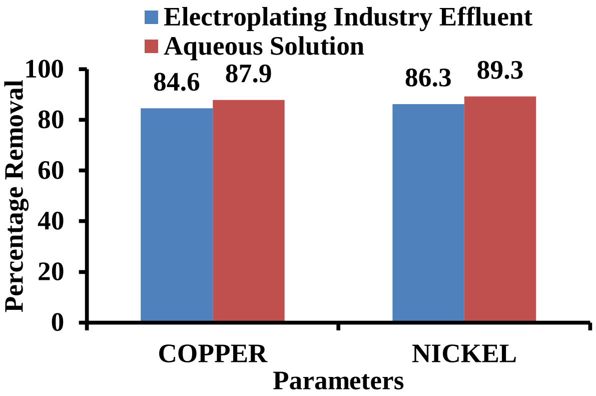

Fig.4 The Percentage Reduction of Cu and Ni in an Electroplating Industry Effluent and Aqueous solution using *Eichhornia crassipes*against Optimum Nutrient Dosage (60 g), Dilution Ratio (10) and pH (8)

The results revealed that the percentage removal of Cu and Ni is low by *Eichhornia crassipes* at the beginning and then increases with nutrient dosage. This is because, the active absorption sites in the supplied nutrient could not be effectively utilized by *Eichhornia crassipes* and thereafter adsorbent sites of nutrient could be effectively utilized by *Eichhornia crassipes*. Up to nutrient dosage 60 g, the absorption of Cu and Ni in a electroplating industry effluent increased by *Eichhornia crassipes* steadily and for the nutrient dosage of 70 g, the percentage removal results showed the resembles of the results obtained nutrient dosage 60 g. Hence, the optimum nutrient dosage found in this study for the maximum removal of Cu and Ni in an electroplating industry effluent by *Eichhornia crassipes* is 60 g.

The absorption of Cu and Ni in a electroplating industry effluent on day 7 and for the nutrient dosage of 70 g, the removal percentage for Cu and Ni was not significant even the contact time and nutrient dosages were higher, it is more likely that an even sufficient contact time available, significant portion of the available active sites remain undiscovered, leading to lower specific uptake by *Eichhornia crassipes* for the nutrient dosage of 70 g and for the contact time of 7 days. Thus, the maximum absorption removal percentage of Cu and Ni in an electroplating industry effluent by *Eichhornia crassipes* against nutrient dosage of 60 g was found to be 84.6 and 86.3 % respectively (Fig.3).

The maximum mass removal of Cu and Ni in an electroplating industry effluent per unit Kg biomass of *Eichhornia crassipes* is 1378.95 and 1052.86 mg/Kg respectively against the optimum nutrient dosage of 60 g. The bioaccumulation factor of *Eichhornia crassipes* for removing Cu and Ni in an electroplating industry effluent was 54.93 and 62.99 respectively. Similarly, the translocation factor of *Eichhornia crassipes* for removing Cu and Ni in an electroplating industry effluent was found to be 1.816 and 2.731 respectively. As similar to dilution ratio and pH, bioaccumulation and translocation were higher for Ni than Cu indicates that Ni uptake by *Eichhornia crassipes* was higher than Cu uptake by *Eichhornia crassipes*.

Verification Experiment: In order to verify the experimental results for the reduction of Cu and Ni in an electroplating industry effluent by *Eichhornia crassipes*, a separate experiment has been performed with an optimum nutrient dosage (60 g), dilution ratio (10), and pH (8) for the removal of Cu and Ni in an aqueous solution by *Eichhornia crassipes*. The maximum removal percentage of Cu and Ni in an electroplating industry effluent and in an aqueous solution by *Eichhornia crassipes* is shown in Fig.4. The initial concentration of Cu and Ni in an aqueous solution is similar to the initial concentration of Cu and Ni in an electroplating industry effluent.

The results (Fig.4) showed that the maximum removal percentage of Cu and Ni in an aqueous solution by *Eichhornia crassipes*is about 87.9 % and 89.3 % respectively. It may be observed from Fig.4 that the result of the removal percentage of Cu and Ni in an aqueous solution is greater than the removal percentage of Cu (84.6 %) and Ni (86.3 %) in an electroplating industry effluent. The Maximum removal of Cu and Ni in an electroplating industry effluent by *Eichhornia crassipes* is presented in Table 1.Similarly, the BAF, TF for the parameters Cu and Ni in an electroplating industry effluent by *Eichhornia crassipes* is presented in Table 2.

From the Table 1 and Table 2, it may be observed that the BAF and TF of Cu and Ni in an electroplating industry effluent and aqueous solution by *Eichhornia crassipes* are greater than 1 and the result of BAF and TF indicated that *Eichhornia crassipes* is potentially useful for remediating Cu and Ni from electroplating industry effluent.

Table.1.Maximum removal of Cu and Ni in an electroplating industry effluent by *Eichhornia crassipes*

Type of Solution	Parameters	$P_{Water,}$ mg/l	$P_{plant,}$ mg/Kg	$P_{shoot,}$ mg/Kg	$P_{root,}$ mg/Kg
Electroplating Industry	Cu	25.102	1378.98	889.442	489.538
	Ni	16.714	1052.86	770.694	282.167
Aqueous Solution	Cu	19.723	1432.77	1040.191	392.579
	Ni	13.054	1089.46	863.942	225.5182

Table.2.BAF and TF for the parameters Cu and Ni in an electroplating industry effluent by *Eichhornia crassipes*

Type of Solution	Parameters	BAF	TF
Electroplating Industry	Cu	54.9351	1.8169
	Ni	62.9927	2.7313
Aqueous Solution	Cu	72.6446	2.6496
	Ni	83.4579	3.8309

The maximum mass removal of Cu and Ni in an aqueous solution per unit Kg biomass of *Eichhornia crassipes* is 1432.77 and 1089.46 mg/Kg respectively against the optimum dilution ratio of 10, pH of 8 and nutrient dosage of 60 g. The bioaccumulation factor of *Eichhornia crassipes* for removing Cu and Ni in an aqueous solution is 72.64 and 83.45 respectively. Similarly the translocation factor of *Eichhornia crassipes* for removing Cu and Ni in an aqueous solution is 2.65 and 3.83 respectively. As similar to bioaccumulation and translocation of an electroplating industry effluent, bioaccumulation and translocation of an aqueous solution were higher for Ni than Cu indicates that Ni uptake by *Eichhornia crassipes* was higher than Cu uptake by *Eichhornia crassipes*.

It was found that maximum removal percentage, BAF and TF for Cu and Ni are higher for aqueous solution than electroplating industry effluent. The reason for maximum removal in an aqueous solution is due to there are no competitive ions present in the aqueous solution than in an electroplating industry effluent, where other several competitive ions available, which are coming from usage of chemicals in various processes. Based on the results, it may be concluded that *Eichhornia crassipes* may be used as sorbents for removing the Cu and Ni in an electroplating industry effluent.

CONCLUSION

In the present study, the experiments were conducted to find out the suitability of *Eichhornia crassipes* forremoving Cu and Ni in an electroplating industry effluent. The ability of *Eichhornia crassipes* for removing Cu and Ni in an electroplating industry effluent was done against various nutrient dosage, dilution ratio and pH against the optimum contact time of 6 days. The maximum percentage reduction of Cu and Ni in an electroplating industry effluent by *Eichhornia crassipes* were obtained at an optimum nutrient dosage of 60 g, dilution ratio of 10 and pH of 8. The results of this study indicated that the maximum removal percentage of Cu and Ni in an electroplating industry effluent was found to be 84.6 and 86.3 % respectively. The results bioaccumulation factor revealed that Ni uptake by the *Eichhornia crassipes*is higher than the Cu uptake. The results of translocation factor revealed that the root of *Eichhornia crassipes* translocate Cu and Ni to shoot of *Eichhornia crassipes*. Further, the results of experiments were validated by conducting the same experiments in an aqueous solution. Thus, this study concluded that *Eichhornia crassipes* was effectively used as phytoextraction of Cu and Ni not only from electroplating industry effluent but also for various types of toxic metal contaminated effluent.

REFERENCES

APHA, AWWA, WEF, Standard Methods for the Examination of water and wastewater, 21st edition. American Public Health Association, Washington DC, 2005.

Erakhrumen, A., and Agbontalor, A., Phytoremediation: an environmentally sound technology for pollution prevention, control and remediation in developing countries. Educational Research and Review, 2(7), 2007, 151-156.

Fischerova, Z., Tlustos, P., Szakova, J., and Sichorova, K., A comparison of phytoremediation capacity of selected plant species for given trace elements. Environmental Pollution, 144, 2005, 93-100.

Ingole, N.W. and Bhole A.G., Removal of heavy metals from aqueous solution by water hyacinth (Eichhornia crassipes). J Water SRT – Aqua, 52, 2003, 119-128.

Shankar, D., Sivakumar, D., Thiruvengadam. M., and Manojkumar, M., Colour removal in a textile industry wastewater using coconut coir pith. Pollution Research EM International, 33(3), 2014a, 499-503.

Shankar, D., Sivakumar, D., and Yuvashree, R., Chromium(VI) removal from tannery industry wastewater using fungi species. Pollution Research EM International, 33(3), 2014b, 505-510.

Sivakumar, D., and Swaminathan, G., Physico-Chemical characteristic of ground water in and around sugar industry. Indian Journal of Environmental Protection, 28(1), 2008, 49-59.

Sivakumar, D., A study on contaminant migration of sugarcane effluent through porous soil medium. Int. J. Environ. Sci. Tech., 8(3), 2011, 593-604.

Sivakumar, D., Adsorption study on municipal solid waste leachate using *moringa oleifera* seed. Int. J. Environ. Sci. Technol., 10, 2012, 113-124

Sivakumar, D., Hexavalent chromium removal in a tannery industry wastewater using rice husk silica. Global Journal of Environmental Science and Management, 1(1), 2014a, 27-40.

Sivakumar, D., Role of low cost agro-based adsorbent to treat hospital wastewater. Pollution Research EM International, 33(3), 2014b, 573-576.

Sivakumar, D., Gayathri, G., Nishanthi, R., Vijayabharathi, V., Sudeshna Das, and Kavitha, R., Role of fungi species in colour removal from textile industry wastewater. International Journal of ChemTech Research. 6(9), 2014a, 4366-4372.

Sivakumar, D., Murugan, N., Rajeshwaran,R., Shobana,T., Soundarya, C., and Vanitha, V.S., Role of rice husk silica powder for removing Cr(VI) in a tannery industry wastewater. International Journal of ChemTech Research. 6(9), 2014b, 4373-4378.

Sivakumar, D., Balasundaram, V., Venkatesan, G., and Saravanan, S.P., Effect of *tamarind kernel* powder for treating dairy industry wastewater. Pollution Research EM International, 33(3), 2014c, 519-523.

Sivakumar, D., Shankar, D., Dhivya, P., and Balasubramanian, K., Bioaccumulation study by *lemna gibba lin*. Pollution Research EM International, 33(3), 2014d, 531-536.

Sivakumar, D., Shankar, D., Gomathi, V., and Nandakumaar, A., Application of electro-dialysis on removal of heavy metals. Pollution Research EM International, 33(3), 2014e, 627-631.

Türker, O.C., Vymazal, J.V., and Türe, C., Constructed wetlands for boron removal: A review. Ecological Engineering, 64, 2014, 350-359.

Zacchini, M., Pietrini, F., Mugnozza, G. and Lori, V., Metal tolerance, accumulation and translocation in poplar and willow clones treated with cadmium in hydroponics. Water. Air. Soil. Pollut., 197, 2008, 23-34.