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Design, Development, and Evaluation of a Laboratory-Scale Phytoremediation System Using Eichhornia Crassipes for the Treatment of Chromium-Contaminated Waters

Diseño, Desarrollo y Evaluación de una Tecnología de Fitorremediación a Escala de Laboratorio Utilizando la Eichhornia Crassipes para el Tratamiento de Aguas Contaminadas con Cromo

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Abstract

Tanneries have become a serious environmental problem due to the lack of cheap water treatment options in the sector. A viable alternative is to implement the macrophyte aquatic plant (Eichhornia crassipes), which has an extensive presence in bodies of water in Cundinamarca, Colombia. The plant has a high invasive capacity, growing uncontrollably in wetlands, lakes, etc. It has the capacity to accumulate and transform organic matter and, especially, to accumulate metals heavy in its morphology. For this study we designed and built a biological (phytoremediation) treatment system for the removal and uptake of chromium in tannery wastewater in the San Benito sector of southern Bogotá. Eichhornia crassipes was the agent of retention of these pollutant compounds, and we concluded that the use of this plant is an economical and technologically feasible solution for the tannery industry.

Keywords: Eichhornia Crassipes, Bioremediation, Chromium, Phytoremediation.

Resumen

El sector de las curtiembres se ha convertido en un serio problema ambiental debido a la falta de alternativas económicas y de fácil acceso para el tratamiento de las aguas de este sector. Una alternativa a implementar es la planta acuática macrófitas (Eichhornia crassipes), la cual tiene una amplia presencia en los cuerpos húmedos de Cundinamarca (Colombia), presentan una alta capacidad invasiva desarrollando un crecimiento descontrolado en humedales, lagunas entre otros, ésta planta tiene la capacidad para acumular y transformar materia orgánica y sobre todo acumular diferentes metales pesados en su morfología. En la presente investigación se diseñó y construyó una tecnología de fitorremediación para la remoción y retención de cromo de aguas contaminadas por los residuos del proceso de las curtiembres en el sector de San Benito sur de Bogotá D.C, siendo la Eichhornia crassipes, el agente retenedor de éstos compuestos contaminantes, donde se evidenció una posible solución económica y tecnológicamente viable para el sector industrial de curtiembres.

***Palabras clave*:** Eichhornia Crassipes, Biorremediación, Cromo, Fitorremediación.

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1. Introduction

The world today is facing a crisis due to the lack of clean freshwater. This scarcity of water is a consequence of the rapid development of industries and the large amount of wastewater from industrial processes that is poured into rivers and water systems. This wastewater often contains a great variety of contaminants, many of them in the form of cationic and anionic ions, oils and fats, and other organic residues with harmful effects on ecosystems. Generally, the removal of these contaminants requires effective technologies, which has led to the development in recent decades of cleaning techniques to address this problem.

The rapid economic and industrial growth has brought serious environmental problems, such as air, water and soil pollution. From an environmental point of view, the mining and tanneries sector have always been classified as high polluters, since their production processes produce chemical compounds such as heavy metals and organic waste that causes toxicity and negative environmental impacts in ecosystems. Chromium, for example, is a chemical agent which has been used in the tannery industry because of the high-quality leather it helps to make. Yet when wastewater containing chromium (Cr) is discharged into the environment it damages it. Chromium removal from wastewater is required to prevent water pollution in rivers [1] [2] and required to comply with current regulations here in Colombia, such as Resolution 631 of 2015.

Chromium (Cr) is one of the most harmful heavy metals on the environment. Hence the effects of its presence in water and soil as well as the potential solutions have become the subject of intensive research in recent years. Under oxidizing, neutral and alkaline conditions, hexavalent chromium (VI) is present as a chromate or a dichromate. In reducing conditions, the conversion of Cr (VI) to Cr (III) can take place. Contamination by inorganic agents such as chromium has serious consequences for both the environment and the health of those who handle it. Studies carried out by Padma and Dhara (2008) [2] found that wastewater from tanneries carries chromium in a state of oxidation (VI) due to the oxidation of Cr (III), thus contaminating soil and water.

Another type of pollution evident is organic pollution through fat waste and liming among other residual products in the leather manufacturing process. These affect the Tunjuelito River ecosystem in Colombia, thus causing the phenomenon of eutrophication. These pollutants also cause bad odors, due to pipe clogging caused by the accumulation of fats, etc.

Moreover, natural ecosystems such as wetlands are abundant in nutrients, water and sunlight. Due to this, it is common to find the presence of certain types of plants that have developed morphological and biochemical adaptations, which enables them to take full advantage of the conditions in their environment. These plants have been commonly called ‘aquatic weeds’. Among these weeds we find the macrophyte species Eichhornia crassipes, popularly known as the ‘water hyacinth,’ which is widely found in in open bodies of water [4] [5].

Through this plant it is possible to build phytoremediation technology to decontaminate water containing chromium [6] [7] [8] [9] [10]. In recent years the species has been shown to be capable of sustainable manipulation in its ecosystem and can be used for the phytoremediation of water contaminated with heavy metals [3] [11] [12] [13]. Along these lines, a variety of types of treatment models have been designed, with great efficacy in the removal of contaminated water [14] [15] [16] [17] [18] [19] [20] [21].

Bioremediation with this plant is an efficient technology for the treatment of contaminated water and is also a low-cost treatment, since it does not require sophisticated infrastructure [22] [23] [24] [25] [26]. It is generally a cheap, simple, sustainable, and environmentally-compatible technology. There are numerous studies worldwide which demonstrate the ability of this plant to remove nutrients, heavy metals and large quantities of organic matter [27] [28] [29] [30] [31] [32] [33]. Studies [1] [7] [13] [34] [35] and [16] evaluated various heavy metals such as mercury, aluminum and others. Furthermore, the authors of [36] [37] [38] and [39] designed this technology for the removal of nutrients in wetlands and obtained significantly positive results.

The main objective of the present project was to design, develop and evaluate new treatment technology for the uptake of chromium by Eichhornia in order to apply this new technology to the tannery sector.

2. Materials and Methods

In this research we employed a quantitative methodology. First we characterized tannery wastewater to establish the degree of contamination. Subsequently, we isolated *Eichhornia crassipes* from a wetland on the outskirts of the city of Bogota, Colombia, in order to carry out the design and assembly of an *Eichhornia* phytoremediation system which will treat wastewater contaminated with organic waste and chromium. Finally, we proceeded to the evaluation through a mass balance, comparing the effectiveness of this removal treatment.

2.1 Characterization of the St. Benedict tanneries wastewater

Until now, there had been no assessment of wastewater from these tanneries, which meant that the exact amount of organic load and contamination by chemicals discharged into the sewer was unknown. We visited the tannery sector multiple times to diagnose the problem. The following diagram, Figure 1, shows the production process of a conventional tannery.

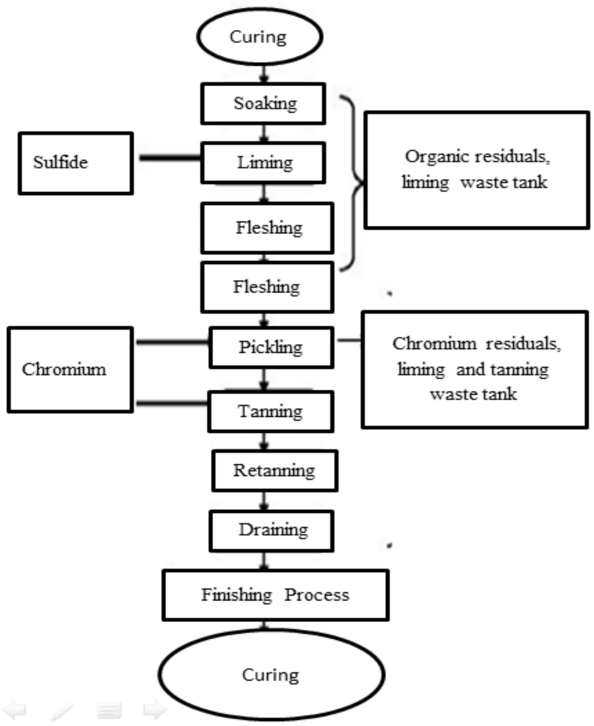

Figure 1 Tannery production process

We proceeded to characterize the tannery wastewater by quantifying chromium contamination and organic waste. Table 1 shows the parameters carried out by an accredited company. The tests were performed in two tanks, one used for tanning and the other used for liming waste, which holds water contaminated with chromium. These discharges occur daily in this tannery.

As shown in the table above, the amount of chromium discharged daily from the liming tank to the sewer is high: more than 1400 mg/L of chromium is a considerably high amount, since regulations indicate that this figure should be less than 1 mg/L. Resolution 631 of 2015 states:

"Whereby the parameters and maximum permissible limit values are set for specific discharges to water body surfaces and public sewer systems and other provisions."

Table 1 Characterization of quality parameters

Parameter	**Units**	**Retanning Tank**	**Liming Tank**	**Limit allowed by Resolution 631 of 2015**
Chromium	mg/L	60	1407	0.5
BOD	mg/L	990	3210	800
COD	mg/L	1245	3664	1500
Fats	mg/L	149	1245	100
Fecal coliforms	NMP/100	$2.5*10^6$	$1.1*10^8$	-
Total coliforms	NMP/100	$6.5*10^6$	$2.5*10^8$	-

The levels of BOD and COD are also very worrying because more is being discharged than expected – 800 mg/L and 1500 mg/L respectively, and there is no control over these discharges. These high rates are the result of fat, blood, and other substances.

This discharge of fat is noticeably very high, a situation which is complicated due to the constant sewer blockages it causes in the area and consequent sewage flooding. The presence of total and fecal coliforms is due to the fact that these tanks are connected to company bathrooms.

2.2 Isolation of Eichhornia crassipes from different wetlands

Table 2 Percentages of distilled water and tannery wastewater

	Tanning wastewater (%)	**Distilled water (%)**
Treatments 2a, 2b and 2c	20	80
Target: 100% water	0	0

Eichhornia crassipes was identified in contaminated waters outside the town of Mosquera, Cundinamarca. Figures 2 and 3 show the location were *Eichhornia crassipes* were found, at coordinates 4.682995, -74.256673.

2.3 Design of phytoremediation technology at a pilot scale using Eichhornia crassipes from water contaminated by the tanneries of San Benito, Southern Bogota

The site is located in the south of Bogota, at the San Benito neighborhood. Figures 2 and 3 show Bogota and the tannery sector.

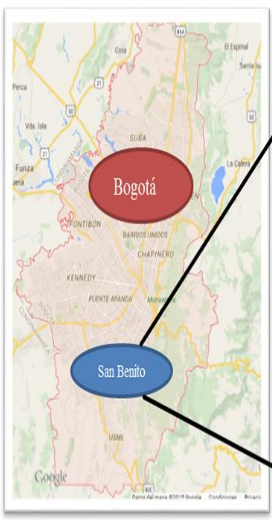

Figure 2 Bogota zoomed in (Source: Google Maps, 2015)

Figure 3 San Benito sector

After the isolation of *Eichhornia crassipes,* it was brought to the laboratory for the experiments. The proposed design consisted of setting up treatment apparatuses three different times, with 20% tannery water, called 2a, 2b and 2c. The remainder was completed with distilled water. A test target was assembled with natural wetlands water for comparison. Wastewater from the tanneries was collected at a company in San Benito in southern Bogota. Table 2 shows a summary of these setups.

The design of each treatment apparatus at the pilot laboratory scale consisted in adapting a resistant plastic container with the dimensions shown in Figure 4.

We used two *Eichhornia crassipes* plants for each treatment, each of which weighted 180g. As seen in Figure 4, the dimensions of this treatment apparatus are: 40 cm in length, 17.5 cm in height and 17.5 cm in width. We also used 11.5 liters of water. This design was made at laboratory-scale.

Figure 4 Design of the treatment apparatus with its dimensions

2.4 Evaluation of the laboratory-scale phytoremediation treatment technology using Eichhornia crassipes

The evaluation of the proposed treatment technology lasted for about one month, as did the experiment in [20]. Hexavalent chromium was measured through spectrophotometry. Table 3 shows the necessary samples for the evaluation of the treatment apparatuses.

Samples of Chromium and BOD were taken at the beginning. During the experiment we measured the degree of concentration of chromium in the water every other day, and at the end of the experiment we measured the BOD. We also measured the degree of accumulation of chromium in plants, by taking 180g of the plants to an oven and then separating the absorbed chromium using a filter, separating it from the ashes and then weighing it. The results showed the amount of chromium in mg out of the 180g sample.

3. Results

The evaluation of these phytoremediation treatment systems was performed by determining the pH, the concentration in mg/L of chromium in the water every two days and the BOD before and after treatment. The amount of chromium found in different *Eichhornia* tissues, especially the stem and root, was also tested. The results were compared with previous research. Three similar treatments were performed, in which the difference between each was negligible. The reliability of these treatment systems was also tested through probability distribution.

Table 3 Sampling water quality

	BOD	Chromium
Treatments 2a, 2b and 2c	Before, and at the end	Every two days
Target	Before, and at the end	-

3.1 BOD removal tests

We performed two water quality monitoring tests on the BOD in each of the treatments. The tests were performed on Day 0 and after 20 days. Figure 5 shows each of these, with the initial and final concentrations of BOD in mg/L.

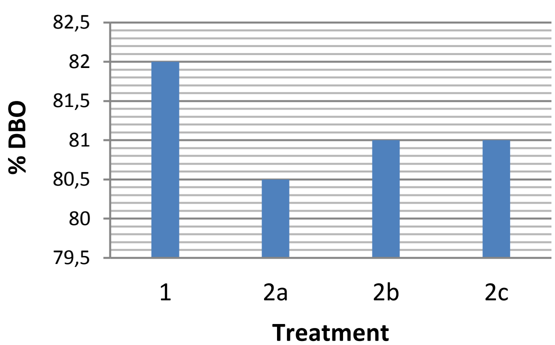

Figure 5 BOD Removal (in %) in each of the treatments

The three treatments yielded very similar results, with removals of 80%. The test target removals reached above 83%. The contributions of nutrients to plants and the oxygenation they provide to the water contribute to the reduction of BOD in tannery wastewater. The treatments (2) were at around 1000 mg/L levels of BOD and the test target was at around 1200 mg/L. The experimentation started with a lack of oxygen in the water represented with a very high BOD level, despite dilutions with distilled water. After the treatment we observed some representative decreases, and in treatments 1 and 2 the BOD lowered to 200 mg/L.

3.2 Chrome evaluation

In order to evaluate our treatment technology we measured chromium concentrations in the water in mg/L, at the beginning and then every two days. Figure 6 shows that chromium concentrations were around 612 mg/L for the initial sample on Day 0 of the experiment. Figure 7 shows that after only two days there was a removal of 33%. There was then a continuous removal which stabilized after 24 ways of treatment.

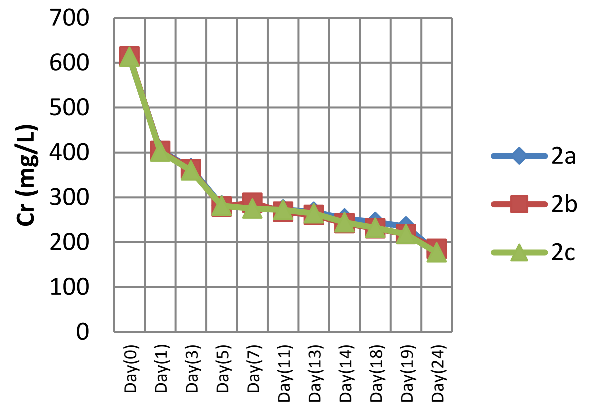

Figure 6 Initial chromium concentrations (612 mg / L)

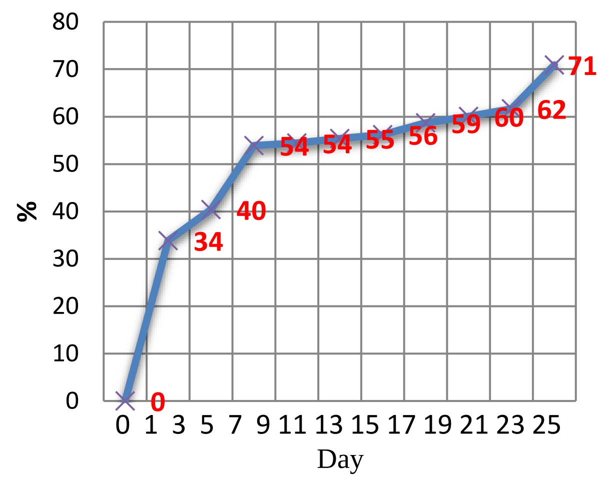

Figure 7 Chromium concentration % removal from initial concentration of 612 mg/L

As shown in Figures 6 and 7 there was an initial removal of 34% on Day 1. It then steadied for several days at over 50%. By the end it showed a final removal of more than 70% on these treatments of 20% tannery water and 80% distilled water. The three tests showed a similar behavior throughout the process and removals were obtained at above 70%.

3.3 Mass balance of chromium

At the end of the *Eichhornia crassipes* treatment process, we tested the aquatic plants for chromium concentration in their vegetative structure. These results show the quantity of chromium in mg in the 180g *Eichhornia crassipes* sample that was used in the three different experiments.

Table 4 shows concentrations of around 4200 (mg chromium / sample) found in the vegetative structure for the three treatments. There were removals because the chromium ended up absorbed within the vegetative structure of the aquatic plant. The reason why the chromium adhered to the plant, or which of its compounds helped (its lignin, cellulose or hemicellulose) is the subject of ongoing research.

Table 4 shows the general balance in each of the experiments of the initial concentrations of chromium, together with the concentrations in the plant and the final chromium concentrations.

Table 4 General balance of chromium in each treatment.

Exp. No.	Initial Chromium (mg)	Final Chromium (mg)	Chromium in *Eichhornia crassipes* (mg of chromium in sample)	Diff.
2a	6120	1880	4200	40
2b	6120	1882	4255	-17
2c	6122	1870	4250	2

In this general balance, we considered the initial and final concentrations and the concentration found in *Eichhornia crassipes*. For the experiment we had 10 liters of water, a combination of both contaminated water and distilled water. At the beginning there was 612 mg of chromium per liter of water. Multiplying 612 mg/L by 10 liters gives a total of chromium in the treatment system of around 6,120 mg.

Using the same procedure, we determined that in the end there were about 1880 mg of chromium remaining in the water. The differences are almost negligible and can be attributed to the uncertainty of the techniques used.

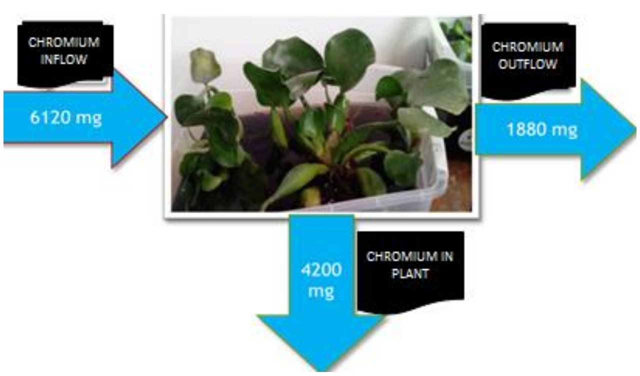

Figure 8 Chromium Balance in experiment 2

As shown in Figure 8, there was a significant removal of chromium; *Eichhornia crassipes* retained a lot of it in its roots and leaves. 70% of the chromium present in the water was removed. This experiment could be potentiated by placing another plant to continue the removals until a permissible level of chromium is reached (one acceptable by the environmental authorities).

4. Conclusions and Recommendations

In order to optimize this process we propose the design of a biological filter using materials made of *Eichhornia crassipes,* by extracting the cellulose of the plant and by chemically modifying zeolites.

Phytoremediation through *Eichhornia crassipes* is an alternative for use as a heavy metal and organic matter retainer due to its high ability to remove these contaminants from water. It is easy to use since this plant is very common in this region.

Due to the high chromium concentrations in tanneries in southern Bogota and resulting saturation and accumulation, it is essential to use various aquatic plants in the treatment system. In this research we evaluated the behavior of the plant with these high concentrations and concluded that in order to optimize the process plants should be alternated, in order to get removals of above 90%.

The contributions of nutrients to plants and the adsorption of carbon sources contribute to the reduction of BOD. Tannery wastewater is loaded with organic waste, raising the levels of COD and BOD, which makes this treatment technology interesting for further research that might optimize the process.

We recommend a cost study evaluating this treatment in the market of conventional treatment plants for use in the tannery sector, in order to determine the feasibility of this treatment.

References

[1] Velarde H; Zavaleta A; Aguilar Q.(2013). Estudio de la absorción del ion cromo vi con jacinto de agua (Eichhornia crassipes). Universidad Nacional de Trujillo. 2 encuentro de investigadores.

[2] Onyanchaa D.; Mavurab J.; Ngilac C. (2008). Studies of chromium removal from tannery wastewaters by algae biosorbents, Spirogyra condensata and Rhizoclonium hieroglyphicum.

[3] Padma S.; Dhara B. (2008). Phyto-remediation of chrome-VI of tannery effluent by Trichoderma species. Padmapriya, G., & Murugesan, A. G. (2015). Biosorption of copper ions using rhizoplane bacterial isolates isolated from Eicchornia crassipes ((Mart.) solms with kinetic studies. Desalination and Water Treatment, 53(13), 3513-3520.

[4] Balasubramaniana,K.Arunachalama,A.K. Dasb,Arunachalama(2012).Decomposition and nutrient release of Eichhornia crassipes (Mart.) Solms. Under different trophic conditions in wetlands of eastern Himalayan foothills.Ecological Engineering 2012.

[5] Anjanabha, P. Kumar. (2010). Water hyacinth as a potential biofuel crop, EJEAFChe 9:1, 112-122.

[6] Zimmels, F. Malkovskaja. (2005).Application of Eichhornia crassipes and Pistia stratiotes for treatment of urban sewage in Israel. Journal of Environmental Management (Impact Factor: 3.19).

[7] Módenes, A. N., Espinoza-Quiñones, F. R., Trigueros, D. E., Lavarda, F. L., Colombo, A., & Mora, N. D. (2011). Kinetic and equilibrium adsorption of Cu (II) and (II) ions on Eichhornia crassipes in single and binary systems.Chemical Engineering Journal, 168(1), 44-51.

[8] Kasturiarachchi, JC. (2014).Removal of nutrients (N and P) and heavy metals (Fe, Al, Mn and Ni) from industrial wastewaters by phytoremediation using water hyacinth (Eichhornia crassipes) under different nutritional conditions.

[9] Alvarado A, Guédez A, Merú. (2008). Arsenic removal from waters by bioremediation with the aquatic plants Water Hyacinth (Eichhornia crassipes) and Lesser Duckweed (Lemna minor). International Journal of Phytoremediation.Volume 16, Issue 12.

[10] Borker, A. R., Mane, A. V., Saratale, G. D., & Pathade, G. R. (2013). Phytoremediation potential of Eichhornia crassipes for the treatment of cadmium in relation with biochemical and water parameters. Emir J Food Agric,25(6), 443-456.

[11] Villamagna, B.R. Murphy. (2010). Ecological and socio-economic impacts of invasive water hyacinth: a review, Freshwater Biology, 55, 282-298.

[12] Brima, P. I. Haris(2014). Arsenic Removal from Drinking Water using Different Biomaterials and Evaluation of a Phytotechnology Based Filter, Int Res. Environment Sci., 3:7, 39 – 44.

[13] Gandhimathi, R., Ramesh, S. T., Arun, V. M., & Nidheesh, P. V. (2013). Biosorption of Cu (II) and Zn (II) ions from aqueous solution by water hyacinth (Eichhornia crassipes). International Journal of Environment and Waste Management, 11(4), 365-386.

[14] Higuera O; Arroyave J; Flórez L. (2008). Diseño De Un Biofiltro Para Reducir El Índice De Contaminación Por Cromo Generado En Las Industrias De Curtido De Cueros. Nro. 160, pp. 107-119.

[15] Gopal, B., 1987. Aquatic Plant Studies 1. Water Hyacinth.Elsevier Publishing, New York, New York, USA.

[16] Epstein P. (2012). Weeds bring disease to the east African waterways. Lancet. Volume 351, No. 9102, p577, 21.

[17] Komy, Z. R., Abdelraheem, W. H., & Ismail, N. M. (2013). Biosorption of Cu 2+ by Eichhornia crassipes : physicochemical characterization, biosorption modeling and mechanism. Journal of King Saud University-Science, 25(1), 47-56.

[18] Xiaosen Li, Songlin Liua, Zhongyuan N, Diannan Lua, Zheng Liu. (2013)."Adsorption, concentration, and recovery of aqueous heavy metal ions with the root powder of Eichhornia crassipes " Ecological Engineering.Volume 60, November 2013, Pages 160–166.

[19] Gupta, A., & Balomajumder, C. (2015). Removal of Cr (VI) and phenol using water hyacinth from single and binary solution in the artificial photosynthesis chamber. Journal of Water Process Engineering, 7, 74-82.

[20] Hadad, H. R., Maine, M. A., Mufarrege, M. M., Del Sastre, M. V., & Di Luca, G. A. (2011). Bioaccumulation kinetics and toxic effects of Cr, Ni and Zn on Eichhornia crassipes . Journal of hazardous materials, 190(1), 1016-1022.

[21] Islam, M. S., Wahid-Uz-Zaman, M., & Rahman, M. M. (2013). Phytoaccumulation of Arsenic Contaminated Soils by Eichhornia crassipes L., Echinochloa Crusgalli L. and Monochoria Hastata L. in Bangladesh. International Journal of Environmental Protection, 3(4), 17.

[22] Gómez, H; Pinzón G. (2012). Análisis de la mitigación del impacto ambiental en el lago del parque la florida, por fitorremediación usando buchón de agua. Tesis de especialización Universidad Militar.

[23] Vásquez B. (2012).El tratamiento de los desechos líquidos de la zona de tintura en las flores para la exportación con Eichhornia crassipes (Buchón de Agua). Revista Lasallista de Investigación; Julio - Diciembre de 2012 Vol.1, No. 2.

[24] Lenka M,Kamal K. Panda ,Brahma B.(1990). Studies on the ability of water hyacinth (Eichhornia crassipes) to bioconcentrate and biomonitor aquatic mercury. Environmental Pollution | Vol 66, Iss1, Pgs 1-101.

[25] Li, Q., Chen, B., lin, P., Zhou, J., Zhan, J., Shen, Q., & Pan, X. (2014). Adsorption of heavy metal from aqueous solution by dehydrated root powder of Long-root Eichhornia crassipes . International Journal of Phytoremediation, (just-accepted), 00-00.

[26] Martínez, C; Torres M, García Cruz. (2013).Evaluación de la cinética de adsorción de zn2+ y cd2+ a partir de soluciones unitarias y binarias por raíces de Eichhornia crassipes y typha latifolia. Vol. 4, Nº. 2, 2013 , págs. 1-14

[27] Chisutia W; Mmari O.(2014). Adsorption of Congo Red Dye from Aqueous Solutions Using Roots of Eichhornia crassipes : Kinetic and Equilibrium Studies. Energy Procedia. Volume 50, 2014, Pages 862–869.

[28] Mohanty, K., Jha, M., Meikap, B. C., & Biswas, M. N. (2006). Biosorption of Cr (VI) from aqueous solutions by Eichhornia crassipes . Chemical Engineering Journal, 117(1), 717.

[29] Mohammed, A. K., Ali, S. A., Najem, A. M., & Kassim, K. (2013). Effect of Some Factors on Biosorption of Lead by Dried Leaves of Water Hyacinth (Eichhornia crassipes). Int. J. Pure Appl. Sci. Technol, 17(2), 72-78.

[30] Xia H, Xiangjuan M. (2006). La fitorremediación de ethion por el jacinto de agua (Eichhornia crassipes) del agua.

[31] Swain, G., Adhikari, S., & Mohanty, P. (2014). Phytoremediation of Copper and Cadmium from Water Using Water Hyacinth, Eichhornia crassipes .International Journal of Agricultural Science and Technology.

[32] Sotolu, A. O. (2013). Management and Utilization of Weed: Water Hyacinth (Eichhornia crassipes) for Improved Aquatic Resources. Journal of Fisheries and Aquatic Science, 8(1), 1-8.

[33] Zanaty R. Komy, Wael H. Abdelraheem , Nabawia M. Ismail (2013). Biosorption of Cu2+ by Eichhornia crassipes : Physicochemical characterization, biosorption modeling and mechanism Chemistry Department, Faculty of Science, Sohag University, Sohag 82524, Egypt

[34] Kumar, N., Bauddh, K., Dwivedi, N., Barman, S. C., & Singh, D. P. (2012). Accumulation of metals in selected macrophytes grown in mixture of drain water and tannery effluent and their phytoremediation potential. Journal of Environmental Biology, 33(5), 923.

[35] Chathuranga, P. D., Priyantha, N., Iqbal, S. S., & Iqbal, M. M. (2013). Biosorption of Cr (III) and Cr (VI) species from aqueous solution by Cabomba caroliniana: kinetic and equilibrium study. Environmental earth sciences, 70(2), 661-671.

[36] Sung, K., Lee, G. J., & Munster, C. (2015). Effects of Eichhornia crassipes and Ceratophyllum demersum on soil and water environments and nutrient removal in wetland microcosms. International journal of phytoremediation, (just-accepted), 00-00.

[37] Ndimele, P. E., Kumolu-Johnson, C. A., Chukwuka, K. S., Ndimele, C. C., Ayorinde, O. A., & Adaramoye, O. R. (2014). Phytoremediation of Iron (Fe) and Copper (Cu) by Water Hyacinth (Eichhornia crassipes (Mart.) Solms). Trends in Applied Sciences Research, 9(9), 485.

[38] Bais, S. S., Lawrence, K., & Nigam, V. (2015). Analysis of heavy metals removal by eichhornia crassipes (mart.) Solms.

[39] Gebregiorgis, F. Y., Struik, P. C., Lantinga, E. A., & Taye, T. (2013). Joint use of insects and fungal pathogens in the management of waterhyacinth (Eichhornia crassipes): Perspectives for Ethiopia. Journal of Aquatic Plant Management, 51, 109-121.

[40] Kanagaraj J.; Chandra B, Mandal B. (2008).Recovery and reuse of chromium from chrome tanning waste water aiming towards zero discharge of pollution.

[41] Hossain R, Chowdhury MK, Yeasmin S, Mozammel. (2010). Production of ethanol using yeast isolates on water hyacinth and azolla. Bangladesh J. International Science Index. Vol 7. No 1. acid hydrolysate to ethanol by Pichia stipites.

[42] Magdum, S.M. More, A.A. Nadaf (2012).Biochemical conversion of acid pretreatment water hyacinth (eichonnia crassipes) to alcohol using pichia stipitis NCIM 3497, International Journal of advanced biotechnology and research, 3:2, 585 – 590.

[43] Menon, M. Rao.(2012). Trends in bioconversion of lignocellulose: biofuels, platform chemicals & biorefinery concept, Progress in Energy and Combustion Science., 38, pp. 522-550.

[44] Mishima D; Kuniki M; Sei B; Soda; Ike M; Fujita M. (2008). Ethanol production from candidate energy crops: Water hyacinth (Eichhornia crassipes) and water lettuce (Pistia stratiotes L.). Bioreosur Tecnhol. 99;2495-2500.

[45] Chuang YS, Lay CH, Sen B, Chen CC, Gopalakrishnan K, Wu JH, (2012) . Biohydrogen and biomethane from water hyacinth (Eichhornia crassipes). International Journal of Hydrogen Energy.Volume 36, Issue 21, October 2011, Pages 14195–14203.

[46] Lay, B. Sen, C.C. Chen, J.H. Wu, S.C. Lee, C.Y. Lin.(2013). Co-fermentation of water hycianth and beverage wastewater in powder and pellet form for hydrogen production, Bioresource Technology, 135, 610-615.

[47] Nath K, D. Das, (2004). Biohydrogen production as a potential energy resource – Present state-of-art, Journal of Scientific & Industrial Research, 63,729 – 738, (2004).

[48] Yeong-Song Chuang , Chyi-How Lay , Biswarup Sen , Chin-Chao Chen Gopalakrishnan Kumar Jou-Hsien Wu , Chih-Shan Lin , Chiu-Yue Lin. (2014). Corrigendum to "Biohydrogen and biomethane from water hyacinth (Eichhornia crassipes) fermentation: Effects of substrate concentration and incubation temperature".

[49] Saraswat J.(2010). Heavy metal adsorption from aqueous solution using Eichhornia crassipes dead biomass. International Journal of Mineral Processing Volume 94, Issues 3–4, 28 April 2010, Pages 203–206

[50] Kumar A; Ghosh S.(2009). Bioconversion of lignocellulosic fraction of water-hyacinth (Eichhornia crassipes) hemicellulose