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EFFICACY OF AQUATIC PLANTS IN INDUSTRIAL EFFLUENT TREATMENT USING VERTICAL SUBSURFACE FLOW CONSTRUCTED WETLAND: STUDIES ON *CERATOPHYLLUM DEMERSUM*, *LUDWIGIA ABYSSINICA* AND *HYDROLEA GLABRA*

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Abstract: Contamination of surface water has become of grave concern due to day to day pollution resulting from various inevitable activities such as industrial, domestic and even agricultural practices involving the use of chemicals. The aim of this study is to treat pulp and paper industrial effluent by phytoremediation using a vertical subsurface flow constructed wetland system. The aquatic plants (*Ludwigia abyssinica, Hydrolea glabra, Ceratophyllum demersum*) were planted in three identical constructed wetlands with the fourth wetland void of plant which served as control. The cells were of dimensions 0.20m x 0.20m x 0.40m in length, width and depth respectively. The base of the cells were filled with gravels of <20mm size to the depth of 0.10m, followed by sand of <0.5mm to the depth of 0.20m and then covered with gravels of <20mm size to the depth of 0.10m. The pulp and paper mill wastewater was introduced into the cells from a storage (sedimentation) tank and operated for a single experimental run with retention time of 7,14,21 and 28 days using batch flow method. The effluent samples were collected at the end of each hydraulic retention time and analysed for Lead, Chromium, Manganese, Zinc, Biological Oxygen Demand, Chemical Oxygen Demand and pH. The results showed that *Ludwigia abyssinica* had the highest removal efficiency with Lead, Chromium, Manganese and Zinc, BOD and COD having 72.81%, 90.72%, 93.30%, 92.11%, 85.07% and 81.48% respectively. *Hydrolea glabra* had removal efficiencies of 63.11%, 78.81%, 90.00%, 65.86%, 80.60%, and 65.08%. *Ceratophyllum demersum* had the lowest removal efficiencies of 48.54%, 56.40%, 81.00%, 58.65%, 74.63% and 61.38%. The pH value for the three plants and control (void of plants) fell within a narrow range of 6.11 - 6.45. These results obtained were very promising to be used in treating industrial wastewater which can be used for fisheries, irrigation and re-use.
Keywords: Constructed wetlands, Aquatic plants, Heavy metals, Industrial effluent

1. INTRODUCTION IN THE STUDY AREA

Kaduna has two seasons, a dry season from November to March and a rainy season from April to October. The mean annual temperature is 25.2ºC. Paladin Factory is situated in the urban capital of Kaduna State and lies between Latitude (10º26'07.9"N) and Longitude (007º24'25.1"E) of the Greenwich Meridian. Paladin Factory has a flow channel approximately 20m in length and 0.4m wide which leads the wastewater generated to the outlet point where it flows down into Romi stream.

2. EXPERIMENTAL SITE SET-UP

The laboratory- scale vertical constructed wetlands were constructed behind the Water Resources and Environmental Engineering Department of Ahmadu Bello University, Zaria to mimic natural weather condition. Four identical glass tubs with dimensions of 0.20m x 0.20m x 0.40m were used. The base of the cells were filled with gravels of <20mm size to the depth of 0.10m, followed by sand of <0.5mm to the depth of 0.20m and then covered with gravels of <20mm size. The gravels were placed at the top to prevent clogging and base of the constructed wetland to ease collection of effluent at the outlet. To check the ability of *Hydrolea glabra* (False fiddleleaf), *Ludwigia abyssinica* (Primrose willow) and *Ceratophyllum demersum* (Hornwort), they were locally sourced, carefully uprooted and hand-planted in the various wetlands. The cells were moist with tap water for two weeks to enable the plants acclimatize to its new environment before wastewater was introduced into the cells. The

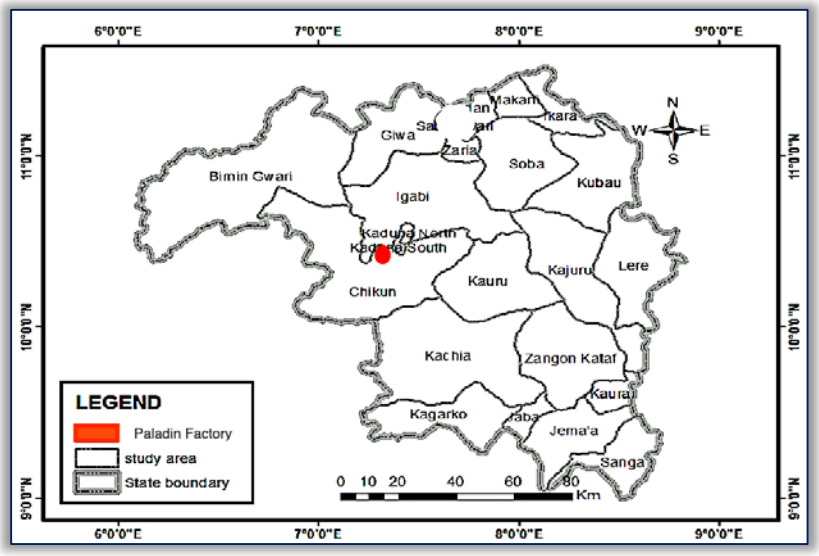


Figure 1: Map of Kaduna showing Paladin Factory

wastewater was regulated by a valve from the storage tank and evenly distributed through polyvinylchloride (PVC) pipes from the storage tank to the cells.

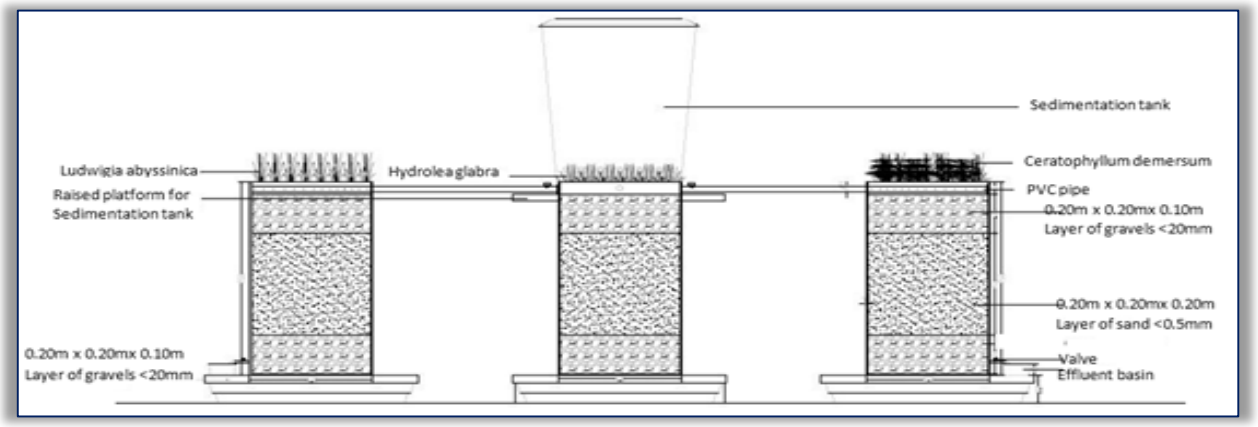


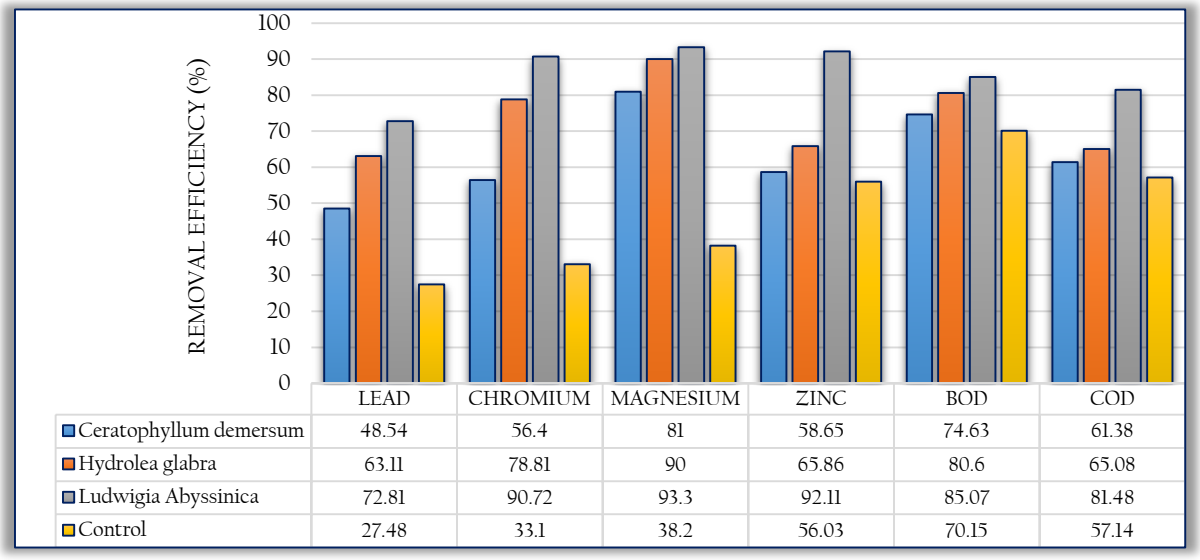
Figure 2: Schematic diagram of Constructed Wetland Design

3. SAMPLE COLLECTION AND ANALYSES

Samples of wastewater obtained from the discharge point of Paladin Factory were collected with the aid of three jerry cans of 25litres capacity. The influent was analysed before it was batched into the laboratory scale constructed wetlands. The effluent samples were collected via the respective taps attached to the cells containing each of the aquatic plants namely: *Hydrolea glabra* (False fiddleleaf), *Ludwigia abyssinica* (Primrose willow) and *Ceratophyllum demersum* (Hornwort) and the Control using clean plastic bottles. The samples were subject to Microwave Plasma Atomic Emission Spectroscopy (Agilent 4200, MP-AES) and analysed for Lead, Chromium, Manganese and Zinc. The pH was determined using a pH meter while the Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) was analyzed using standard methods. The removal efficiency was calculated according to the method employed by Ugya *et al.*, (2015).

4. RESULTS AND DISCUSSION

— Lead: The reduction efficiency of Lead was higher for *Ludwigia abyssinica* compared to other plants 72.81% as shown in Figure 3. This removal efficiency is in line with the results reported by Hossein, *et al.*, (2014) who recorded lead removal efficiency of 60.05%. *Hydrolea glabra* had a significant removal efficiency of 63.11% and *Ceratophyllum demersum* had the least removal efficiency of 27.48%. The result is in accordance with Schneider and Rubio (1999) who indicated that the result for *Ceratophyllum demersum* had low metal adsorbtion compared to other aquatic plants, but Keskinkan., *et al.* (2004) who compared the values of heavy metals in *Ceratophyllum demersum* with the values in other research stated contrary that *Ceratophyllum demersum* can be very effective in heavy metal removal compared with other aquatic plants and this does not agree with the current study.



	LEAD	CHROMIUM	MAGNESIUM	ZINC	BOD	COD
Ceratophyllum demersum	48.54	56.4	81	58.65	74.63	61.38
Hydrolea glabra	63.11	78.81	90	65.86	80.6	65.08
Ludwigia Abyssinica	72.81	90.72	93.3	92.11	85.07	81.48
Control	27.48	33.1	38.2	56.03	70.15	57.14

Figure 3: Removal Efficiency at Day 28

— Chromium: *Ceratophyllum demersum* had the least overall percentage removal of about 33.10%, *Hydrolea glabra* had an overall percentage removal of about 78.81%. With the highest removal efficiency recorded for *Ludwigia abyssinica* having 90.72%. Although, 99.5% removal efficiency was reported in Chromium removal using *Eichornia crassipes* by Priyanka *et al.*, (2017).

— **Manganese**: *Ludwigia abyssinica* in 28 days had a percentage removal of 93.30%. *Hydrolea glabra* had 90.00% removal efficiency and *Ceratophyllum demersum* was the least with overall percentage removal of 81.00% efficiency. A similar study of the removal efficiency of Manganese was recorded by Ugya, (2015), who observed a 94.30% treatment using *Lemna minor*.

— **Zinc**: The removal efficiency results for Zinc were 92.11%, 65.86%, 58.65% and 56.03% for *Ludwigia abyssinica, Hydrolea glabra, Ceratophyllum demersum* and Control respectively. Although, Srivastav *et al.*, (2007) observed that the removal efficiency of Zinc fell within the range of 50 – 95% for both *Spirodela* and *Salvinia* aquatic plants.

— **pH**: The pH readings of the influent and effluent are represented in Table 1. The three aquatic plants and the control reduced the pH to WHO effluent discharge standards with *Ludwigia abyssinica* reducing the pH to 6.45, *Hydrolea glabra* reduced the pH to 6.30 while *Ceratophyllum demersum* reduced the pH to 6.20 and Control reduced the pH to 6.11. The influent and effluent pH values range between 5 – 7, which agrees with Crossley (2012), who found that most aquatic macrophytes prefer pH in the range of 5 – 7.5 and can also tolerate a range of pH levels but they vary in their tolerance.

— **BOD**: BOD removal efficiency from the wetland was significant at the end of 28 days retention time showing, *Ludwigia abyssinica, Hydrolea glabra, Ceratophyllum demersum* and control having 85.07%, 80.60%, 74.63% and 70.15 respectively. These results conform to a similar study carried out by Tripathi and Shukla (1991) who reported over 96% reduction in BOD using *Eichornia crassipes* and algae for sewage treatment. The Control actively reduced the concentration of the BOD to a 70% removal efficiency rate which might be triggered by settling of suspended solids in the wetlands.

Table 1: Influent and Effluent Concentrations of the Measured Parameters from the Constructed Vertical Subsurface Flow Wetland Using Batch Flow.

Parameters	Influent	Effluent using Aquatic macrophytes																WHO Standards
		Ceratophyllum demersum				*Ludwigia abyssinica*				*Hydrolea glabra*				Control				
		7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days	
pH	5.20	5.49	5.77	5.93	6.20	5.64	6.03	6.29	6.45	5.57	5.94	6.22	6.30	5.37	5.41	5.89	6.11	6-9
BOD	67	36	26	22	17	28	22	16	10	32	28	18	13	42	30	23	20	50
COD	189	118	101	86	73	98	82	52	35	105	89	71	66	132	116	98	81	180 *
Lead (mg/l)	0.41	0.36	0.30	0.28	0.21	0.31	0.23	0.13	0.11	0.32	0.27	0.19	0.15	0.39	0.34	0.32	0.30	0.05
Chromium (mg/l)	0.47	0.31	0.25	0.26	0.21	0.21	0.20	0.17	0.04	0.23	0.24	0.19	0.10	0.43	0.36	0.34	0.32	0.1
Manganese (mg/l)	1.05	0.09	0.08	0.06	0.05	0.08	0.06	0.02	0.02	0.08	0.07	0.04	0.02	0.19	0.18	0.17	0.16	1.0
Zinc (mg/l)	4.46	2.91	2.41	2.11	1.85	1.55	1.02	0.79	0.35	2.54	2.15	1.82	1.52	3.06	2.84	2.34	1.96	5.0

* – EPA Effluent Standard for Paper Producing Industry using Waste Paper as Raw Material (Above 60%)

Table 2: Anova Test Result Using Batch Flow

Plants	Source of Variance	SS	df	MS	F	P-value	F crit
Luwigia abyssinica	Between Groups	12258.82	6	2043.137	22.45745	4.03E-08	2.572712
	Within Groups	1910.541	21	90.97812			
Hydrolea glabra	Between Groups	21704.73	6	3617.454	53.15676	1.29E-11	2.572712
	Within Groups	1429.104	21	68.05258			
Ceratophyllum demersum	Between Groups	28289.68	6	4714.947	63.09046	2.40E-12	2.572712
	Within Groups	1569.396	21	74.73313			
Control	Between Groups	36158.35	6	6026.392	63.42781	2.28E-12	2.572712
	Within Groups	1995.248	21	95.01182			

— **COD**: The COD removal efficiency results by the constructed wetlands for *Ludwigia abyssinica, Hydrolea glabra* and *Ceratophyllum demersum* were 81.48%, 65.08% and 61.38% which falls within the range of result by Vymazal, (2013), who reported COD maximum efficiency removal of 59 -93%.

The analysis of variance (ANOVA) tool was carried out at 5% significant level ($p < 0.05$) to determine the removal efficiency of each plants in the constructed wetlands and Table 2 shows that the ANOVA result of the Vertical Subsurface flow using the Batch flow is statistically significant with P value <0.05.

5. CONCLUSIONS

Current study reports that effluent of Paladin factory contain different concentration of heavy metals above the permissible limits. Heavy metals affect in various ways causing stunted growth in plants, heath threat to aquatic life and humans when injested. Conventional techniques available to reduce/remove heavy metals from wastewater are proven to be highly expensive and incure reoccurring expenditure. Phytoremediation techniques could be a cost-effective and ecofriendly technique for heavy metal uptake from industrial effluent and the removal efficacy of *Hydrolea glabra*, *Ludwigia abyssinica* and *Ceratophyllum demersum* through phytoremediation could be a promising techniques to remove/reduce heavy metals in industrial wastewater.

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