ASSESSMENT OF THE EFFICIENCY OF DIFFERENT MIXES OF MACROPHYTES IN REMOVING HEAVY METALS FROM WASTEWATER USING CONSTRUCTED WETLAND

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Abstract

Industrial wastewater has high quantities of heavy metals emanating from industrial processes. These heavy metals need to be removed before the wastewater is released to the environment. Constructed wetlands are inexpensive and highly effective in removal of heavy metals from wastewater. This study assessed the efficiency of different mixes of macrophytes *Polygonum spp, Typha latifolia and Papyrus cyperus (X,Y,Z)* to remove zinc, lead and cadmium from municipal wastewater using constructed wetlands. The model wetlands were wash basins with an outlet at the bottom. A total of 16 basins were used, 12 of which were planted and 4 unplanted to act as control (4 treatments with 3 replicates). Quarry dust (¼") was used as the substrate in each basin. 12 plants (X,Y,Z) were planted in mixes of 1:1:1, 2:1:1, 1:2:1 and 1:1:2 respectively. Wastewater was collected from Thika municipal treatment works and analyzed for Zinc, Lead and Cadmium using Atomic Absorption Spectrophotometer before being introduced into the wetlands. Samples from the wetlands were collected after 4, 6 and 8 days for analysis for several runs. Plant samples were harvested and concentration of heavy metals determined. The results showed that treatment with more of *Polygonum* spp achieved highest removal for Zinc (80.5%), treatment with more of *papyrus* achieved the highest removal for Lead (89.8%) while maximum removal for Cadmium was achieved when the macrophytes were in equal ratios. The treatment with 6 *Polygonm spp, 3 Typha spp* and 3 *Papyrus spp* recorded relative high removal rates for all metals and was recommended as the best mix. The analysis of the metals in the macrophytes indicated increasing absorbance; *Papyrus spp >Typha spp >Polygonum spp.* The concentrations of the Zinc and Cadmium in the effluent sewage were below the maximum allowable concentrations for discharge into the environment. The constructed wetlands were therefore effective in reducing the heavy metals concentrations from the raw sewage to tolerable levels.

Key words: Constructed wetland, heavy metals, macrophytes, atomic absorption spectrophotometer

1 Introduction

Wastewater treatment and disposal in developing countries have always been a major environmental challenge due to high costs of conventional wastewater treatment systems caused by high construction and chemicals costs, poor maintenance of facilities and often lack of trained human resource. The dire need for proper sanitation, improved health standards and protection of the scarce water resources from pollution thus calls for low cost but effective wastewater treatment systems like constructed wetlands. Constructed wetlands have been found to significantly improve sanitation, reduce construction costs and use relatively low skilled labour.

Wetlands are transitional areas between land and water. The boundaries between wetlands and uplands or deep water are therefore not always distinct. The term "wetlands" encompasses a broad range of wet environments, including marshes, bogs, swamps, wet meadows, tidal wetlands, floodplains, and ribbon (riparian) wetlands along stream channels (Davis, undated; UN-HABITAT, 2008).

Constructed wetland (CW) is a biological wastewater treatment technology designed to duplicate processes found in natural wetland ecosystems. Constructed wetlands can serve as wastewater treatment systems and always consist of shallow ponds or channels planted with aquatic macrophytes. They can treat a variety of wastewaters by the microbial, biological, physical and chemical processes (Hamilton, *et al*., 1997). A constructed wetland consists of a properly designed basin that contains water, a substrate (crushed rock, gravel, organic material like compost) and, most commonly, macrophytic plants.

Different mixes of three common macrophytes,*Typha latifolia, Papyruscyperus*and *Polygonum spp*. were used to investigate their efficiency in removal of selected heavy metals (zinc, lead and cadmium) from wastewater collected from Thika Municipal Treatment plant.
Though many constructed wetlands use single species macrophytes, natural wetlands usually consist of a mix of different species of macrophytes. This project was therefore undertaken with the knowledge that individual performances of these plants had previously been assessed with the aim of comparing the individual performance with the results obtained when different mixes of the same macrophytes are used (Home et al., 2010).

2 Problem Statement

Wastewater treatment is a key problem in developing countries, which contaminates the water bodies thereby increasing health risk to the population. Continued existence of these countries depends upon the sustainable use and quality maintenance of water natural resources (Aslam *et al*, 2010). Conventional wastewater treatment plants involve large capital investments and operating costs in form of the inputs, chemicals, energy and skilled labour *(*Ciria *et al*., 2005*).*Lack of finances for such projects has been the major contributor towards poor wastewater treatment and disposal in developing countries. Combinations of these factors have lead to compromised sanitation, public health, poor nutrient recovery in the ecosystems and pollution of freshwater resources.

The effectiveness of the constructed wetland has been demonstrated through industrial wastewater treatment using such wetlands (Kadlec and Knight, 1996). Bioaccumulation of heavy metals in the human systems can be carcinogenic and /or mutagenic. The options like Ecotechnological treatment like constructed wetland treatment are now recognized as possible options for wastewater treatment as they are cost effective and simple in technology (Cooper *et al*., 1996). Many researchers have assessed the efficiency of different species of macrophytes individually and obtained satisfactory results, however with statistically different efficiencies in comparison (Claudia Bragato *et al,* 2008; Aslam *et al*, 2010; Eloy Bécares, 2006).

2.1 Justification

Constructed wetland fit in the criterion of low-cost and effective waste water treatment technology on the basis of:

i. Low capital investment during establishment
ii. Low maintenance and operational costs
iii. No energy consumption
iv. Non requirement of highly skilled labour
v. Utilization of local flora which is freely available

Constructed wetlands are easily incorporated in the urban setting in addition to the cost benefit over the conventional sewage treatment methods. Developing countries in tropical climates have an edge over other countries in terms of cheaply available land and good climatic conditions favoring the growth of macrophytes, algae and bacteria. The result of this project showed the best (most efficient) mix of the macrophytes to be used in constructed wetlands; this data will help designers to come up with optimal designs for CWs based on local data for Kenyan situation.

Constructed wetlands have been proven to remove both organic and inorganic contaminants in municipal waste water*.* The remediation of wastewater containing heavy metals has assumed great relevance in the last decades. Unlike organic pollutants, metals do not undergo degradation and generally need to be removed through highly expensive clean-up methods. As an alternative, phytoremediation is a biological, low-cost and environmental friendly clean-up technology, which can be exploited for heavy metal removal (Claudia Bragato *et al.,* 2008).

The knowledge that statistically different results have been obtained for individual macrophytes' performance raises the interest in experimenting with different macrophytes in the same constructed wetland. This also closely simulates the natural wetlands condition where different macrophytes exist. This project is part of the wider vision of reducing the number of people without proper sanitation and access to clean water by half by the year 2015. This will be achieved by enhancing the database in support for CW as a cheaper wastewater treatment method in Kenya.

3 Objectives

2.2 General objective

To evaluate the efficiency of different compositions of macrophytes in a constructed wetland for removal of heavy metals (Zn, Pb and Cd) from wastewater.

2.3 Specific objectives

a) To determine the removal rates of the heavy metals in different mixes of macrophytes in a constructed wetlands.
b) To determine Zn, Cd, and Pb uptake by the different macrophytes species in the constructed wetlands.
c) To assess the effect of retention time in removal of the heavy metals in the constructed wetlands.

4 Methodology

4.1 Establishment of macrophytes and the wetland

The constructed wetland took the form of wash basins (models) modified with an outlet at the bottom. In the models, a substrate in the form of quarry dust (gravel ground upto ¼") 12 cm thick was used in each basin model. Different mixes of macrophytes were then planted in the models. In the first 7 weeks of planting the plants were fed by normal clean water to allow stable establishment after which raw sewage was introduced. The models were kept under roof to avoid dilution from rain water.

4.2 Mixing ratios and replicates

12 plants at different mixes were established in 3 replicates. 4 controls (where no plants were planted) were also established. Table 1 shows the experimental layout of the different treatments, with the designation as A: B: C *Typha latifolia: Papyruscyperus*: *Polygonum spp* macrophytes. Figure 1 shows the constructed wetlands at the start of the experiment.

Table 1: The experimental layout showing different mixes and the number of each plant used in the experiment

Mix	Set up 1	Set up 2	Set up 3	Set up 4
	A: B: C 1 : 1 : 1	A: B: C 2 : 1 : 1	A: B: C 1 : 2 : 1	A: B: C 1 : 1 : 2
Treatments Number of Plant A:B:C	3:3:3	6:3:3	3:6:3	3:3:6
Replicates	2	2	2	2
Control experiment	Not planted	Not planted	Not planted	Not planted

A = *Typha latifolia, B = Papyruscyperus,* C = *Polygonum spp.*

Figure 1: A pictorial representation of the experimental set up

4.3 Wastewater Collection

Wastewater samples were collected in Thika sewerage treatment works in the secondary ponds when main organics had settled to avoid these organics from clogging the system.

4.4 Introduction of Wastewater in The Models

After the plants had established.

4.5 Sampling

Sampling of the wetland effluent was carried out after 4, 6, and 8 days retention times. The samples were taken to the laboratory for analysis of heavy metal (Zinc (Zn), Cadmium (Cd) and Lead (Pb)) content using Atomic Absorption Spectrophotometer (AAS) machine.

4.6 Lab Analysis

4.6.1 Analysis of Effluent from Wetland

The samples were filtered first to remove suspended filterable materials using normal filter paper. The AAS machine was then calibrated for zinc, cadmium and lead and calibration curves obtained. The samples were run in the machine and their absorbencies obtained. From the calibration curves the concentrations of the samples were obtained. Calibration curves are shown as appendices 1.

4.7 Analysis of Raw Sewage

Before the raw sewage was fed into the models, the heavy metal contents were established so as to lay a basis of comparison.

4.8 Analysis of Macrophytes

After the experiment was completed, the biomass of the individual macrophytes in the treatments that showed maximum removals were harvested, dried, digested in concentrated sulfuric acid and analysed for heavy metals in the AAS machine.

5 Results and Discussion

5.1 Lead Removal

Table 2 shows lead concentration in raw sewage and in the effluent from the constructed wetlands after different retention periods for the different treatment set ups. The Table indicates increased Pb removal with the retention time. After 8 days retention, Set up 3 which had 3 *Polygonum, 3 Typha and 6 Papyrus* reeds had the maximum removal 89.8 % of the lead in the original raw sewage. The actual concentration was 0.201 mg/l. This combination of plants is therefore the most efficient in wetlands where the raw influent has high concentrations of lead metal to be removed.

Table 2: Lead (Pb) concentration in the raw and effluent sewage after different retention periods and the corresponding % removal in different treatments

Retention period (Days)	%removal of Lead by the wetlands Treatments							
	Set up 1		Set up 2		Set up 3		Set up 4	
	Conc. mg/l	% removal	Conc. mg/l	% removal	Conc. mg/l	% removal	Conc. mg/l	% removal
Raw water Conc.	1.900	100.0	1.900	100.0	1.900	100.0	1.900	100.0
4	0.700	63.2	0.801	58.2	0.610	67.9	0.878	54.0
6	0.531	72.1	0.609	67.9	0.479	75.0	0.630	66.9
8	0.322	83.4	0.359	81.3	0.201	89.8	0.481	75.0
Control At day 8	Concentration of control basins (unplanted) after 8 days retention =0.602 mg/l which is 68.4% removal							

5.2 Cadmium Removal

Table 3 shows cadmium concentration in raw sewage and in the effluent from the constructed wetlands after different retention periods for the different treatments. Cadmium concentration in the raw water is generally lower than other metals. This can be attributed to lesser industrial activities in Thika that generate cadmium in their waste effluent. After 8 days retention, set up 4 which had equal proportions of all the 3 macrophytes had the maximum removal at 88.5 % and therefore was the most efficient for use in wetlands in treating water high in Cadmium concentration. The final concentration was 0.0045 mg/l.

Table 3: Cadmium (Cd) concentration in the raw and effluent sewage after different retention periods and the corresponding % removal in different treatments

Retention period (Days)	%removal of Cadmium by the wetlands Treatments							
	Set up 1		Set up 2		Set up 3		Set up 4	
	Conc. mg/l	% removal	Conc. mg/l	% removal	Conc. mg/l	% removal	Conc. mg/l	% removal
Raw water Conc.	0.0390	100.0	0.0390	100.0	0.0390	100.0	0.0390	100.0
4	0.0227	41.9	0.0198	49.4	0.0166	57.4	0.0135	65.35
6	0.0166	57.4	0.0135	65.4	0.0106	72.9	0.0076	80.7
8	0.0076	80.7	0.0076	80.7	0.0061	84.5	0.0045	88.5
Control At day 8	Concentration of control basins (unplanted) after 8 days retention =0.0120 mg/l which is 69.2% removal							

5.3 Zinc Removal

The removal % of zinc by the constructed wetlands was generally lower than for Pb and Cd (Table 4). This trend of absorbance conforms to the selectivity series for metal uptake by plants in the order: Cr > Pb > Cu > Cd > Zn > Ni (Gomes et al., 2001). After 8 days retention period, the maximum % removal was 80.4%, with a final effluent concentration of 0.254 mg/l. This maximum removal was achieved by set up 1: 6 *Polygonum, 3 Typha and 3 Papyrus* reeds. This mix of macrophytes therefore is the most efficient for use in wetlands treating water high in zinc concentration.

Table 4: Zinc (Zn) concentration in the raw and effluent sewage after different retention periods and the corresponding % removal in different treatments

	%removal of Zinc by the wetlands							
Retention period (Days)	Treatments							
	A		B		C		D	
	Conc. mg/l	% removal	Conc. mg/l	% removal	Conc. mg/l	% removal	Conc. mg/l	% removal
Raw water Conc.	1.300	100.0	1.300	100.0	1.300	100.0	1.300	100.0
4	0.745	42.7	0.777	39.0	0.845	35.0	0.884	32.0
6	0.642	50.7	0.674	48.2	0.714	45.1	0.702	46.0
8	0.254	80.5	0.329	74.7	0.458	64.8	0.477	63.3
Control At day 8	Concentration of control basins (unplanted) after 8 days retention =0.520 mg/l which is 60% removal							

5.4 Maximum Removal and Allowable Limits

Table 5 gives a comparison of the obtained concentrations in the wetland to the allowable NEMA limits. Zinc and cadmium were satisfactorily removed both by the wetland and in TMTW from the raw water to allowable standards; however no wetland was able to remove lead to allowable limits. The removal of lead by the wetlands was significantly higher than that by TMTW. Lead removal rate however, was the highest at 89.8%. This could only mean that the concentration of lead in the raw sample was very high and more efficient and complete removal required a longer retention time (longer than 8 days) or a larger volume of substrate. A raw concentration of 1.9mg/l is quite high for Pb. This concentration should not have been in a public sewer since it exceeds the required amount of 1 mg/l for discharge into a public sewer.

Thus, wetland treatment is a viable and cheaper option to remove heavy metals to meet the required regulatory standards.

Table 5: Maximum removal and NEMA allowable limits

Metal / initial concentration		Conc. (mg/l) Wetland outlet	% removal in wetlands	Conc at Thika outlet (mg/l)	NEMA max Allowable limit	Comment
Pb 1.9mg/l	Treat. C	0.2010	89.8%	0.7758	0.01	Exceed limit
Zn 1.3 mg/l	Treat. A	0.2540	80.5%	0.2730	0.5	Adequate
Cd 0.039mg/l	Treat. D	0.0045	88.5%	0.0066	0.01	Adequate

5.5 Removal of Metals per Treatment

Figure 2 below details the various performances of different treatments on removal of individual metals and also the effect of the unplanted control.

The treatments:

A: 6 *Polygonum, 3 Typha and 3 Papyrus* reeds

B: 3*Polygonum, 6 Typha and 3 Papyrus* reeds

C: 3*Polygonum, 3Typha and 6 Papyrus* reeds

D: *Equal proportions of all the 3 macrophytes*

From the Figure 2 the maximum removals for Pb, Cd, and Zn was in treatments C, D and A, respectively. Minimum removals for Pb, Cd, and Zn were in treatments D, A and D respectively.

Treatment A showed the highest removal rates for all the metals On average at 81.5% followed by treatment C at 79.1%, treatment BAT 78.9 % and lastly treatment D with 75.6%. Treatment A is therefore concluded as the most efficient to use in wetlands for heavy metals removal from waste water. Though the removal rates seem relatively close the test of significance for the means at one (1) and five (5) percent gave highly significant figures. This indicated that there was a significant difference between the treatments.cAll the controls depicted high removal rates > 60% for all the 3 metals meaning that the bulk of the treatment can be attributed to the adsorption by substrate material (quarry dust).

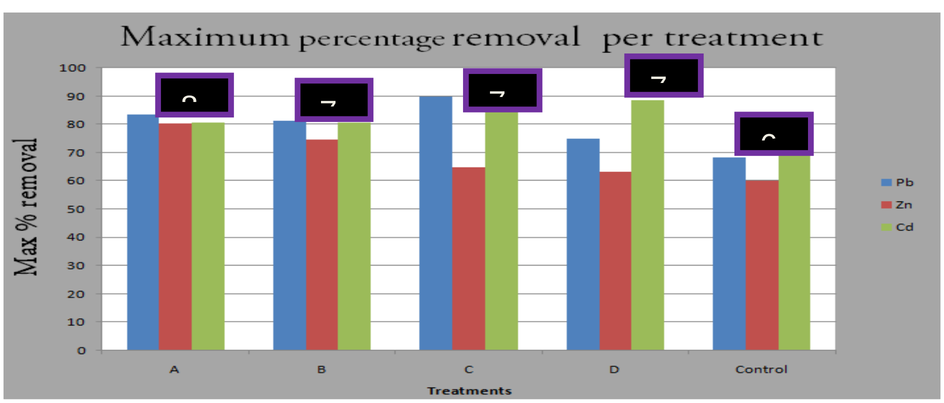

Figure 2: The maximum percentage removal of the heavy metals per treatment

5.6 Harvested Macrophytes

Polygonum plant had highest conc. of Zinc at 0.2381ppm compared to background plant with 0.0018ppm (>130 times increase). The order of zinc absorption by the macrophytes was: *Polyginum spp>Papyrus spp>Typha spp.* Papyrus was the highest in Lead uptake with an initial concentation of 0.0005ppm while in the final concentration in the plant material was 0.1342 ppm (>260 times). The order of lead absorption by the macrophytes was: *Papyrus spp>Typha spp>Polygonum spp.* Papyrus again had the highest uptake rates for cadmium, initially there was no trace of cadmium in the background plant but the final concentration of cadmium in *Papyrus spp* was 0.0031 ppm. The order of cadmium absorption by the macrophytes was; *Papyrus spp>Typha spp>Polygonum spp. Typha spp* was observed to have an intermediary position in the general series of heavy metal removal. Therefore *Papyrus spp* is the best macrophyte for metal removal, followed by *Typha spp* and lastly *Polygomun spp.*

6 Conclusions and Recommendation

6.1 Conclusions

The results of this study have shown that the wetlands are suitable alternatives for the treatment of the wastewater. The rate of removal varied according composition or the mixes of macrophytes used in the wetlands. Treatment C; 3 *Polygonum, 3 Typha and 6 Papyrus* reeds plants was the most effective for Lead removal (89.8%) therefore can be used in wetlands which receive influent with high amounts of Lead. Treatment A; 6 *Polygonum, 3 Typha and 3 Papyrus* reedsplants was the most effective for Zinc removal(80.5%) and therefore can be used in wetlands which receive influent with high amounts of Zinc. Treatment D; equal proportions of all plants was the most effective for Cadmium removal (88.5%) and therefore can be used in wetlands which receive influent with high amounts of cadmium. Treatment B; 3 Polygonum, 6 Typha , 3 Papyrus reeds did not have extreme removal values.

No particular wetland treatment was most effective in removal of all metals however treatment A(6 *Polygonum, 3 Typha and 3 Papyrus)* recorded relative high removal rates for all metals i.e., (Pb (83.4%), Zn (80.5%) and Cd (80.7%) an average of 81.5% and is hence recommended as the best mix for treatment in wetlands.

*Papyrus spp*is the best macrophyte for metal removal, followed by *Typha spp* and lastly Polygomun *spp. Papyrus spp* absorbed the highest amounts of Pb and Cd while Polygonum was the best in Zn. Maximum removal of heavy metals from wastewater was obtained after 8 days of retention time. However this does not mean that the removal stopped at day 8. Higher removal rates should be expected with increase in retention time until an optimum is achieved. Quarry dust, the substrate achieved relatively high rates of removal (65.9%) of the metals compared to the macrophytes. Most of the absorption in the wetland was effected by the substrate adsorption.

6.2 Recommendations

The level of treatment achieved in these wetlands are not wholly attributable to individual macrophytes but the combination of these plants. Therefore it is recommended that a good mix of macrophytes should be maintained in constructed wetlands. This resembles the natural wetlands. Wetlands can best be applied to pre-treat industrial effluent before discharge into public sewers and as a form of tertiary treatment before discharge into the environment. Further research is recommended using continuous flow of waste waster rather than batch system and development of an adsorption isotherm for quarry dust.

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