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Removal of heavy metals from wastewater by a constructed wetland system at Egerton University, Kenya

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Abstract: *The use of constructed wetlands for wastewater treatment has been proposed as an intermediate technological solution for handling wastewater. The aim of the study was to assess the efficiency of a constructed wetland at Egerton University, Kenya for heavy metals removal from wastewater. The wetland has been used for tertiary treatment of effluent from waste stabilization ponds system since 2007. An investigation was conducted between August 2013 and January 2014. Water samples were collected from the wetland and analysed for selected heavy metals (Pb, Cu, Cd and Zn) using Atomic Absorption Spectrophotometry (AAS). Temperature, pH, electrical conductivity and dissolved oxygen were also measured. Results indicated that the concentration of cadmium was below the detection limit. Influent levels of lead, copper and zinc were 1.25 mg/L, 1.09 mg/L and 0.15 mg/L respectively during the study period. The wetland effectively reduced Pb by 94%, Cu by 70% and Zn by 100%. Dissolved oxygen was generally low and did not show any significant difference in concentration across the wetland; while temperature, pH and electrical conductivity values in effluent were lower than in the influent. The study findings indicate that the constructed wetland was performing its function of heavy metal removal from wastewater.*

Key Words: *Constructed wetland, Heavy metals, Removal efficiency, wastewater.*

I. Introduction

Water is an essential resource for life which greatly influences our public and environmental health as well as providing the pedestal for most of our economic activities. Unsustainable use of fresh water resources, population increase, and the trend in industrial revolution have led to environmental degradation especially by the release of partially treated or untreated wastewater into aquatic systems. Thus, the global freshwater resource is at risk and majority of the problems that humanity face in the twenty-first century are related to water quantity and/or water quality issues [1]. Treatment of wastewater is a basic component in any community to protect the health and the environment of communities [2]. However, many developing countries lack adequate wastewater treatment facilities and the existing ones are either mal-functional or overstretched in terms of capacity [3]. In some developing countries, only about 10 per cent of domestic wastewater is collected for treatment and recycling, and only about 10 per cent of wastewater treatment plants operate efficiently [4]. Waste stabilization ponds are popular for treating wastewater in tropical and subtropical regions because of the abundant sunlight and high ambient temperatures [5]. Their widespread use in the tropics is also partly due to their cost-effectiveness and high potential of removing different pollutants. Further, they are relatively easy to operate and require minimal maintenance [6].

Lately, universities are being seen as ‘small cities’ due to their large size, population, and the various complex activities taking place in campuses, which may have serious direct and indirect impacts on the environment [7]. Thus wastewater generated from these institutions contain a wide range of contaminants that may include heavy metals, detergents, pesticides, pathogens, hydrocarbons, pharmaceuticals etc., which may prove difficult to treat effectively within existing wastewater treatment systems.

Metal contamination is an emerging issue of environmental and human health concern due to the adverse effects that heavy metals may have on aquatic and terrestrial organisms globally [8]. Anthropogenic activities including sewage and storm water discharges, landfills, mining and smelting, electroplating, laboratories, tanning, battery manufacture, electronic waste disposal are the main sources of metal pollution in aquatic and terrestrial ecosystems. Heavy metals are of great concern to human health particularly because of their ability to bio-magnify, bio-accumulate and persistence in the environment [9]. In humans, heavy metals exposure above threshold levels may result in developmental, immunological and neurological disorders, several types of cancer, kidney damage and endocrine disruption [10]. The most widely used conventional methods for removing heavy metals from wastewater include ion exchange, chemical precipitation, reverse osmosis, evaporation, and membrane filtration. However, most of these methods suffer from some drawbacks, such as high capital and operational cost or the disposal of the residual metal sludge [11].

Wastewater treatment by waste stabilization ponds systems cannot eliminate pollutants such as heavy metals and pathogens. Wetlands are seen to achieve better treatment of wastewater, including the removal of heavy metals, suspended solids and pathogens, unlike the conventional treatment systems which are reported to only partially remove the above pollutants [12]. Constructed wetlands (CWs) have been used over the last five decades for treatment of wastewater from various sources in virtually all regions of the world. CWs are engineered systems that have been designed and constructed to take advantage of natural processes involving wetland vegetation, soils, and the associated microbial assemblages to assist in treating wastewaters [13]. Treatment process wetlands occurs through a combination of complex natural, chemical, physical and biological processes, including sedimentation, precipitation, adsorption, assimilation by plants and microbial activity [14].

This study aimed at evaluating the performance of the constructed wetland in removing heavy metals (Pb, Cu, Cd and Zn) from pre-treated effluent from a waste stabilization pond system that treats wastewater generated at Egerton University. This study was conceived after previous studies indicated deterioration of effluent quality in levels of nutrients (phosphorus and nitrates) and pathogens [15, 16].

II. Study Area

Egerton University, Kenya is located about 25 Km south-west of Nakuru town in Nakuru County (Figure 1). The institution stands on about 1580 hectares of land within the River Njoro watershed at an altitude of 1890 - 2190 M above sea level. This is an agricultural area characterized by bimodal precipitation pattern ranging from 760 - 1270 mm per annum where long rains fall from March – May while the short rains occur in September - November and experiences a temperature range of 14.9 - 21.9 °C.

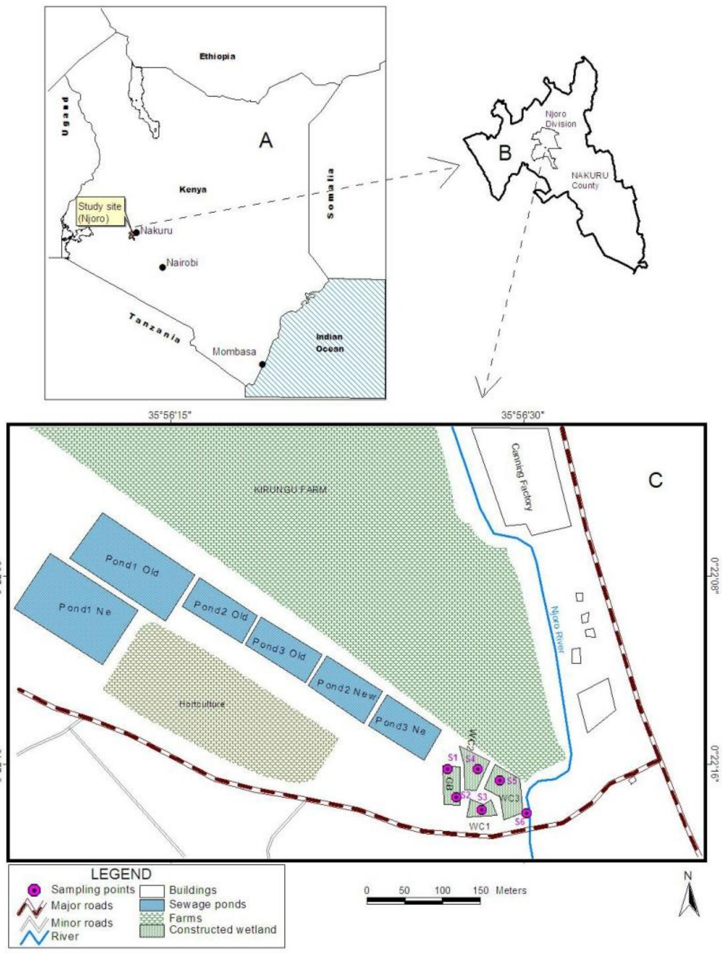

Figure1. Map of the study area and sampling points on the Egerton University constructed wetland.

Egerton University has a population of about 18,000, and generates about 800 m^3 /day of wastewater which is treated in waste stabilization ponds (lagoons) within the University. A free-water surface wetland was constructed in 2007 to polish the pre-treated wastewater effluent from the waste stabilization ponds. The system consists of one vegetated sedimentation/gravel bed dominated by *Pistia stratiotes*; other species included *Cyperus alopecuroides* and *Scirpus lacustris.* This compartment is followed by a series of three connected, vegetated wetland cells. The dominant plant species in the first two cells was *Eichhornia crassipes*, while the last cell was largely an open pond with few tufts of *Cyperus alopecuroides.* The system was designed to purify about $100m^3$ of water per day with an approximate detention time of 10 to 14 days before discharging into River Njoro which is one of the rivers that feed Lake Nakuru – a Ramsar site as well as a UNESCO designated World Heritage site [17].

III. Materials And Methods

3.1 Sampling and analysis of water samples

Samples were collected monthly for a period of six months from August, 2013 to January, 2014. Six sample points (S1-S6) were selected from inlet to the outlet of the wetland. Samples were collected between 10.00 and 12.00 hours using one litre pre-cleaned sample bottles. From each point, three one-litre samples of water were collected, labelled, acidified to pH < 2 using concentrated nitric acid [18], then transported to the laboratory for analysis. A total of 96 water samples were collected and analysed during the study period. In every sampling session; temperature, pH, electrical conductivity (EC) and dissolved oxygen (DO) of water samples were measured in situ using an electrochemical analyser (Jenway model 3405). In the laboratory, duplicate samples of 30 mL each of the water samples were measured into 100 mL conical flasks followed by 10 mL of hydrochloric acid: water (1:1) and 2 mL nitric acid: water (1:1) solutions. The samples were digested on a hot plate until the volume reduced to about 25 mL. The samples were then cooled to room temperature, filtered and made up to 50 mL in volumetric flasks using deionized water and the concentrations of heavy metals including Lead (Pb), Copper (Cu), Cadmium (Cd) and Zinc (Zn) determined using an Atomic Absorption Spectrophotometer (Thermo Jarell Ash S11 AAS). Data was managed using Minitab statistical software package. Assumptions of normality and homogeneity of variance were determined using Kolmogorov-Smirnov and Levene's tests, respectively. One-way analysis of variance (ANOVA) was used to determine any significant differences in means for the measured parameters. All statistical tests were carried out at 95% significance level. The efficiency of heavy metals removal by the wetland was calculated by comparing the inlet and outlet mean concentrations of the metals.

IV. Results and Discussion

4.1. Physico-chemical parameters of the influent to the wetland and treated wastewater across the wetland

Measurement of physico-chemical parameters of water samples during the study period showed the following levels across the wetland:

Table 1: Physico-chemical parameters of water at different sites in the wetland (Mean ± SE)

Site	Temp (ºC)	EC(µS/cm)	DO (mgL^{-1})	pH
S1	18.59 ± 0.24	781.22 ± 9.33	4.73 ± 0.82	8.10 ± 0.05
S2	18.40 ± 0.24	797.44 ± 10.00	2.19 ± 0.33	7.60 ±0.05
S3	17.86 ± 0.26	802.33 ± 7.91	2.36 ± 0.43	7.47 ± 0.06
S4	17.30 ± 0.31	781.72 ± 8.25	2.18 ± 0.4	7.18 ± 0.07
S5	18.10 ± 0.29	771.39 ± 11.79	4.28 ± 0.66	7.35 ± 0.07
S6	18.15 ± 0.64	776.17 ± 0.11	3.15 ± 0.11	7.46 ± 0.04
NEMA (MPL)	-	-	-	6.5-8.5

NEMA (MPL) **-** National Environment Management Authority (Kenya) Maximum Permissible Limits

The highest mean temperature was observed at site S1 (18.59 ± 0.24) and the lowest in S4 (17.3 ± 0.31). Water temperature varied significantly ($p < 0.05$) across the wetland during the study period. The decrease of temperature from S2 to S4 was attributed to the cooling effect due to vegetation cover. The temperature rise in S5 was because the site was basically an open pond with little vegetation while S6 is the outlet of this pond. Temperature plays a critical role in the chemistry and biochemical reactions in organisms as well as many other processes in the wetland [19].

Electrical conductivity values ranged between a mean of 771.39 ± 11.79 µS/cm in S5 and 802.33 ± 7.91 µS/cm in S3 and varied significantly along the wetland cells ($p < 0.05$). The increase in conductivity in S2 and S3 may be due to sedimentation hence the sites act as deposits of ions. Electrical conductivity is a useful indicator of the total dissolved solids in water [20].

Dissolved oxygen levels were generally low in the wetland, ranging between 2.18 ± 0.4 mgL^{-1} in S4 and 4.73 ± 0.82 mgL^{-1} in S1. This may be attributed to high oxygen demand by decomposing organic matter in the wetland as well as the dense mats of floating macrophytes. The rise of DO in S5 may have resulted from the decrease in oxygen demanding wastes that previously consumed dissolved oxygen in S2, S3 and S4. Dissolved oxygen is essential for survival of aerobic aquatic organisms and influences many chemical reactions. DO standard for sustaining fish and aquatic life is 4-5 mg/L [21].

pH remained slightly alkaline across the wetland. Influent pH was 8.10 ± 0.05 and 7.46 ± 0.04 at the outlet. A significant variation in pH was observed across the wetland cells ($p < 0.05$). The decrease in pH could be attributed to carbon dioxide released from breaking down of organic wastes by bacteria and organic acids resulting from decaying vegetation [22]. However, pH of effluent was within the National Environment Management Authority (Kenya) standard of 6.5 – 8.5 for discharge into the environment.

4.2. Concentrations of metals in the influent to the wetland and wastewater water at different points along the wetland.

Sample analysis for the heavy metals in water showed the following mean concentrations across the wetland system (Cadmium was not detected in all samples):

Table 2: Metals concentration in water samples at different sites in the wetland (Mean ± SE)

Site	Pb (mg/L)	Cu (mg/L)	Zn (mg/L)
S1	1.2525 ± 0.7553	1.0878 ± 0.4944	0.15167 ± 0.1077
S2	0.6958 ± 0.8599	0.7930 ± 0.4098	0.09598 ± 0.0893
S3	0.9742 ± 0.8599	0.8744 ± 0.5638	0.08411 ± 0.0894
S4	0.8350 ± 0.8721	0.9649 ± 0.6066	0.05039 ± 0.0686
S5	0.6958 ± 0.8599	0.9904 ± 0.6564	0.03359 ± 0.0478
S6	0.0696 ± 0.0696	0.32472 ± 0.1117	ND
NEMA (MPL)	0.1 mg/L	1.0 mg/L	0.5 mg/L
% Reduction	94.44	70.15	100

NEMA (MPL) **-** National Environment Management Authority (Kenya) (Maximum Permissible Limits
ND **-** Not Detected,

Lead concentration was highest at the inlet to the wetland (S1) but dropped in the sedimentation/gravel bed (S2) before rising again in S3 then dropped steadily across the wetland profile (Figure 2). Analysis of variance (ANOVA) showed no significant difference in mean concentration of the lead metal across the wetland ($p > 0.05$). Lead removal efficiency was 94.44% with levels of concentration decreasing from 1.2525 ± 0.7553 to 0.0696 ± 0.0696 mg/L. Lead level in the effluent was within the NEMA (National Environment Management Authority - Kenya) maximum permissible limits of 0.1 mg/L for discharge into the environment.

Copper followed a similar trend as lead but the variation pattern in the wetland differed after S3 where the concentration continued to rise through to S5 then dropped drastically in S6 (Figure 2). Copper indicated no significant variation across the wetland ($p > 0.05$) although the concentration reduced by 70.15% with levels dropping from 1.0878 ± 0.4944 to 0.32472 ± 0.1117 mg/L, which was below the NEMA's MPL of 1.0 mg/L for discharge into the environment.

Zinc levels were also highest at S1 like lead and copper, but reduced steadily and significantly ($p < 0.05$) across the wetland profile. Zinc reduced by 100% with levels dropping from 0.15167 ± 0.1077 mg/L to non-detectable level.

Generally, the reduction of metal levels in wastewater can be attributed to the chemical, physical and biological processes occurring in the wetland that include, sedimentation, precipitation, adsorption, assimilation by plants and microbial activity [23]. The variation of mean concentrations of Pb, Cu and Zn in water across the wetland is illustrated in Figure 2.

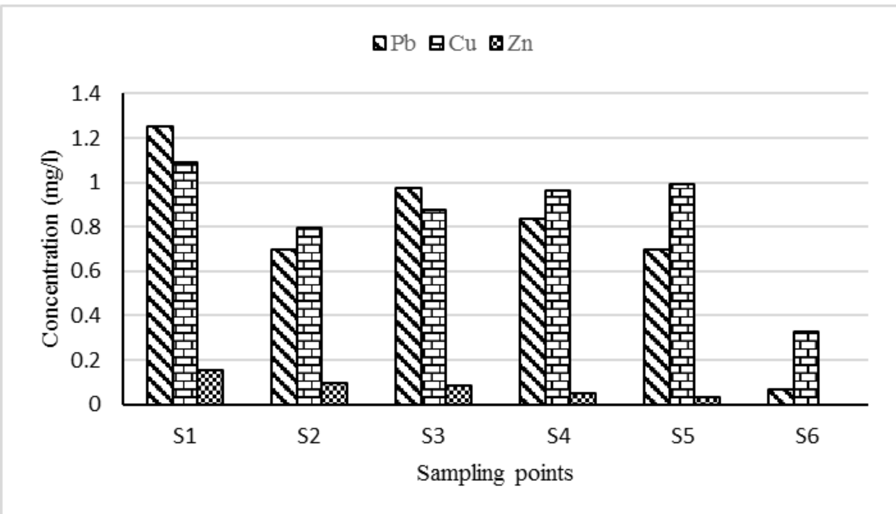

Figure 2. Metals concentration in water samples across the wetland profile.

The concentrations of the metals were highest in S1 (inlet) before any influence by the wetland. A drop in concentrations was observed in S2, the sedimentation/gravel bed. This may be attributed the settling of suspended particles onto whose surfaces the metals are adsorbed. Sedimentation is recognised as the main process in removal of heavy metals from wastewater in constructed wetlands. However, other chemical processes like precipitation and co-precipitation have to occur first [24]. Lead concentration increased in S3 before dropping steadily in the subsequent sites. There is a possibility that lead may have been released back to water column from the sediments. It has been reported that physico-chemical factors such as pH, redox potential, or temperature change can cause metals in the sediment to be released back into the water column causing secondary pollution [25]. Copper exhibited a steady increase from point S2 to S5 before dropping at the outlet. Copper has a high affinity for binding to organic matter e.g. humic acids to form stable compounds [26]. However, when the organic matter is biodegraded the adsorbed metals may be released back to the water column. The increase of copper levels in S3 to S5 could also be associated with run-off from the surrounding horticultural demonstration fields. Zinc showed a steady decrease along the wetland until it was not detected at the outlet.

Studies conducted on a similar constructed wetlands used for wastewater treatment have shown that constructed wetlands offer a viable option or can supplement the conventional methods. At Nandi Hills tea estates, Kenya, heavy metals removal efficiencies of 80.0%, 95.1% and 100% for Pb, Cu and Zn respectively have been reported [27]. Another study at Kingfisher constructed wetland in Naivasha, Kenya, reported heavy metal removal efficiencies of 25%, 50% and 73.1% for lead, copper and manganese respectively [28].

V. Conclusion

The study revealed that with the exception of cadmium and zinc, lead and copper were present in effluent from the wastewater stabilization ponds at levels above the prescribed limits of the National Environment Management Authority-Kenya (NEMA) for effluent discharge into the environment. However, effluent from the constructed wetland contained lead, copper and zinc at levels that are below NEMA's MPL and therefore considered safe for discharge into the environment. Consequently, it was established that the constructed wetland was performing its function of heavy metal removal from the wastewater. The wetland, however, requires rehabilitation and maintenance for optimum and sustained performance.

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