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Potential of Vetiver Grass (*Chrysopogon zizanioides*) in Phytoremediation of Kipevu Wastewaters

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ABSTRACT

Wastewater treatment worldwide has mainly been done using physical, chemical and biological treatment systems such as activated sludge and biological nutrient removal technologies. Mombasa produces large amounts of pollutant-laden effluent water that is collected and primarily treated and discharged into the Indian Ocean. Various pollutants such as nitrates, phosphates, zinc and cadmium in water bodies pose a threat to the aquatic species. The aim of this study was to explore the potential of vetiver grass as a phytoremediation technology to minimise pollutants in water bodies. Field experiments were carried out using plastic containers of five litres which were set-up simultaneously with planted grass hydroponically. Wastewater was characterized for physicochemical parameters before and after treatment with the grass. The parameters studied were: effects of vetiver on reduction of pollutants with time and effect of biomass (number of Vetiver plants) on treatment efficiency. Wastewater had high levels of Chemical Oxygen Demand (1440 mg/L), Biological Oxygen Demand (75 mg/L) nitrates (775 mg/L), phosphates (25 mg/L) and Total Dissolved Solids (1432 mg/L) , which were beyond the maximum contaminable levels. A drastic increase in the pollutants uptake with time was observed. The levels of nitrates, phosphates, chemical oxygen demand, biological oxygen demand and total dissolved oxygen reduced by 89.76%, 85.6%, 84.51%, 69.33% and 16.76% respectively over 28 days. During the same period, a direct correlation in the reduction of Chemical Oxygen Demand and nitrates with increased number of plants was observed. The potential of vetiver grass after four weeks hydroponic treatment was found to be efficient in the reduction of pH, nitrates, phosphates, total nitrogen, total phosphorous, total dissolved solids, chemical oxygen demand and biological oxygen demand. The study recommends that vetiver grass be introduced in the aeration tanks to improve the efficiency of Kipevu waste water treatment plant.

***Keywords**: Wastewater, Vetiver, hydroponic, phytoremediation.*

INTRODUCTION

Humans are inducing environmental changes in the planet as a whole in fact, the human fingerprint is extensively visible on the global atmosphere, the oceans and land (Miller, 2006). Clean water is increasingly becoming one of the most scarce and valuable resources in the twenty-first century. This is because its supply is finite and its traditional source is easily polluted by industries and population growth. The production and discharge of untreated wastewater is rapidly increasing in Kenya, most especially in Mombasa city, due to population growth, urbanization, and economic development. However, lack of investment capacity for construction and operation of adequate treatment facilities (Van Lier & Lettinga, 1999). Consequently, it threatens the quality of surface water, soils and groundwater to which wastewater is discharged. The treatment of these wastewater effluents has not been given due attention to date. One of the reasons for the lack of attention is the capacity and the cost associated with the construction and operation of wastewater treatment plants (Bedewi, 2010). Wastewater has serious negative impact not only on underground, surface water bodies and land in the surrounding area but also on the aquatic ecological system (Gebre-Mariam & Beshah, 2002). Treatment of wastewater has mainly been done using physical, chemical and biological wastewater treatment systems such as activated sludge and biological nutrient removal technologies. However, these technologies are expensive and depend on power source and skill hence conventional treatment technologies are either ineffective or wasteful and costly (Nhapi, 2004; Oron, 1994). Many studies on phyto-remediation technologies are on-going, of the many plant species that have been widely studied, Vetiver grass (*Vetiveria zizanioides*) has been identified to be of significant potential (Njau & Mlay, 2003; Liao et al., 2003).

Vetiver (*Chrysopogon zizanioides*) belongs to Order Poales and Family Poaceae (Mcmahon, 2014).The Vetiver system depends on the use of this unique tropical plant which can be grown over a very wide range of climatic and soil conditions. If planted correctly, it can be used virtually anywhere under tropical, semi-tropical, and Mediterranean climates. It has characteristics that in totality are unique to a single species. When Vetiver grass is grown in the form of a narrow self-sustaining hedgerow it exhibits special characteristics that are essential to many of the different applications that comprise the Vetiver system. It has unique morphological and physiological characteristics. Vetiver has been successfully used in the field of environmental protection. It is excellent for the removal of heavy metals from contaminated soil (Roongtanakiat & Chairoj, 2001) and rehabilitating landfills (Roongtanakiat *et al.*, 2003). Even though it is not an aquatic plant, Vetiver can be established and survive under hydroponic conditions. It can purify eutrophic water, garbage leachates and wastewater from pig farms (Kong et al., 2003). Therefore, Vetiver has high potential to be used for wastewater treatment.

MATERIALS AND METHODS

The main experimental materials used were Vetiver plants, and municipal wastewater collected from the aeration tanks of Kipevu Waste Water Treatment Plant (WWTP). The vetiver plant tillers were sourced from Voi in Taita-Taveta County.

The research was conducted at Kipevu WWTP between August 2015 and January 2016. The plant is located at Changamwe Sub County in Mombasa County. The study area is described by latitude 4°03’16’’S, longitude 39°39’48’’E.

The sampling of wastewater in the treatment plant was done just before the water enters the aeration tanks. 90 litres and 200 litres of waste water were collected for the first and second set of the experiment respectively. Five litres of effluent waste water were poured into each of the 12 plastic containers of five litre capacity. Three sampling bottles (500 mL each) were also filled with untreated wastewater for characterization. The effect of treatment time on water quality was studied by planting hydroponically two plants in a 5 L volume of wastewater per treatment. The three treatments were replicated thrice and 500 mL volume sampled for chemical analysis at 7, 14, 21 and 28

Fig. 1: Treatment time experiment

days (figure 1). The experiments were carried out between August and September 2015.

Variation of biomass was studied by planting hydroponically four (4), eight (8) and twelve (12) plants in a 5 L volume of wastewater (figure 2). The three treatments were replicated thrice and sampled for physico-chemical analysis. The experiment was carried out between December and January 2016.For each treatment of biomass there were twelve observations making a total of thirty six observations 7, 14, 21 and 28 days.

Fig.2: Biomass experiment

The influent and effluent were sampled at seven-day intervals and analyzed for Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Nitrates, Phosphates Total Nitrogen (TN), Total Phosphorus (TP) and Total Dissolved Solids (TDS) according to standard methods for water and wastewater analysis (Eaton, 2005). The collected data was analysed using one way analysis of variance (ANOVA) to test for the significant difference between effluent wastewater pollutant levels of the different treatments.

RESULTS AND DISCUSSIONS

The results of physicochemical analysis of Kipevu raw wastewater are shown in Table 1. The values were compared to the maximum permissible limits of effluent waste water set by NEMA (EMCA, 2015).

The pH, Zinc, Cadmium and EC values of the wastewater met NEMA effluent standards. Other heavy metals were below detectable levels. The low concentration of heavy metals could be as a result of the source of the wastewater at that period of sampling. The concentration of pollutants varies from time to time because the plant receives waste water from different sources thus close monitoring of these pollutants is required. However, the average concentration levels of BOD_5 and COD were above NEMA Maximum Contamination Level (MCL) limits by 60% and 2880% respectively.

Table 1: Physico-chemical parameters of Kipevu Wastewater

Parameter	Units	Value	NEMA MCL
pH	pH units	7.81	6.5-9.0
EC	µS/cm	1573	2000
BOD_5	mg/L	75	30
COD	mg/L	1440	50
TDS	mg/L	1432	1200
TN	mg/L	138	-
TP	mg/L	13.45	-
Nitrates	mg/L	775	45
Phosphates	mg/L	25	5
Ammonia	mg/L	1.22	100
Cadmium	mg/L	0.007	0.1
Zinc	mg/L	0.0216	5

The high BOD_5 and COD may be due high concentration of organic matter present in the wastewater released from different sources of waste water in the treatment plant. The high level of BOD_5 indicates the pollution strength of the wastewaters and low oxygen availability for living organisms in the wastewater when utilizing the organic matter present in the wastewater. High COD level implied that there was high oxidizable wastes that require very high dissolved oxygen. The COD: BOD_5 ratio is an important indicator of the biodegradability of the pollutants in wastewater. The results showed a ratio of 19.2 (i.e. 1440/75=19.2). If the ratio is less than two (<2), the load is considered easily biodegradable ((Rehm et al., 1999). Therefore, in this study the ratio of COD to BOD_5 is »2 hence the pollutant load was not easily biodegradable.

The study found out that the wastewater at the Kipevu plant contained 775 mg/L nitrates and 25 mg/L phosphates. These were above the minimum NEMA contaminable limits of 45 mg/L and 25 mg/L. The high concentration of nitrates may be due to the discharge of animal and human wastes with decaying organic matter. High phosphates levels in the wastewater could possibly be the result of soaps being used in washing places, restaurants, industries and showers which drains into the treatment plant.

In general, the results of this analysis indicated that high level of contamination of the wastewater with both organic and inorganic pollutants. The concentration of BOD_5, COD, Nitrates, Phosphates and EC were found to be beyond the maximum level of their respective permissible values set by NEMA. Thus, this wastewater requires treatment before discharging into the environment.

The study found that pH reduced by 0.77% in the first week, 1.42% in the second week, 2.09% in three weeks and 3.44% in four weeks. A 72% reduction was realised in the entire four weeks. The pH values of Vetiver sets were slightly lower than the control set in all treatment time (figure 3).

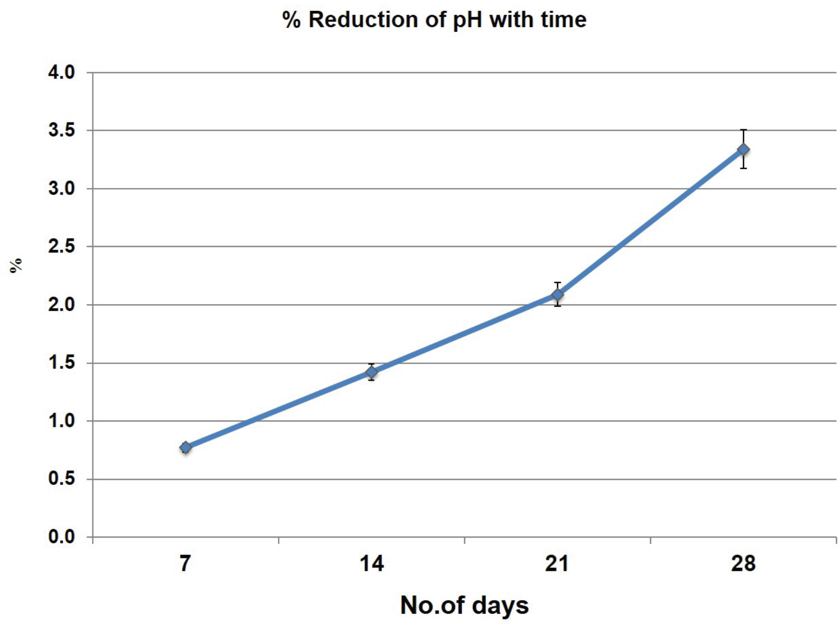


Fig.3: Percentage reduction of pH with time

The analysis of variance on the net reduction amounts coming from Vetiver and control treatment during the entire experiment period on pH was statistically significant (p = 0.027).

Vetiver treatment resulted in lower pH value (7.23) compared to that obtained under the control treatment (7.81). From these finding, it is clearly evident that higher organic matter decomposition rate resulting in CO_2 and acid production lowered the pH values of the wastewater under Vetiver treatment (Bedewi, 2010).

COD concentrations were also reduced from 1440±1 mg/L at the establishment of experiment to 38.19% in one week, 27.53% in two weeks, 28.22% in three weeks and 51.84% in four weeks. Cumulatively percentage removal was 84.51% in four weeks treatment. BOD_5 reduced from 75±1 to 14.76% in one week, 25.56% in two weeks, 34.04% in three weeks and 38.71%. 74.67% was the cumulative percentage reduction. Moreover, during the entire time series analysis it could be depicted that the concentration of BOD_5 and COD of experimental sets planted with Vetiver were lower than the control set (Figure 4).

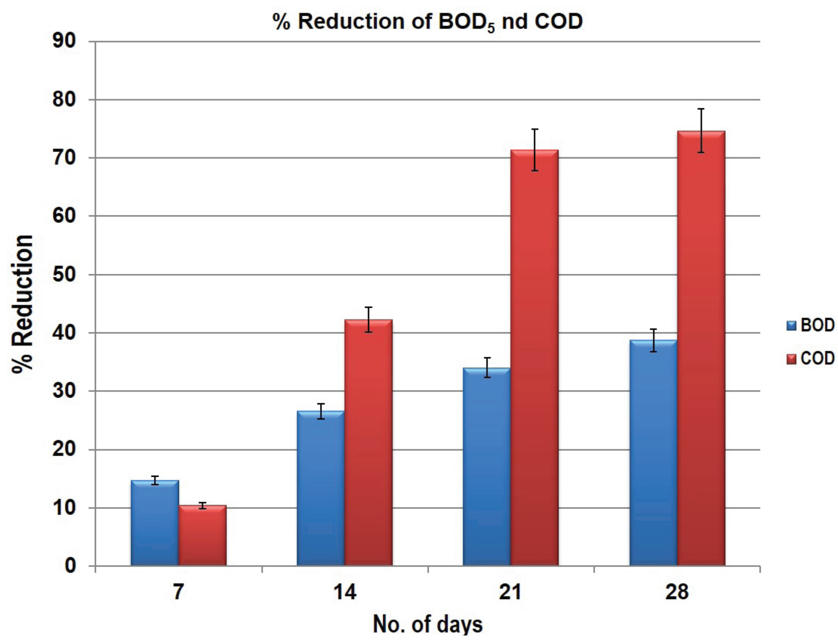


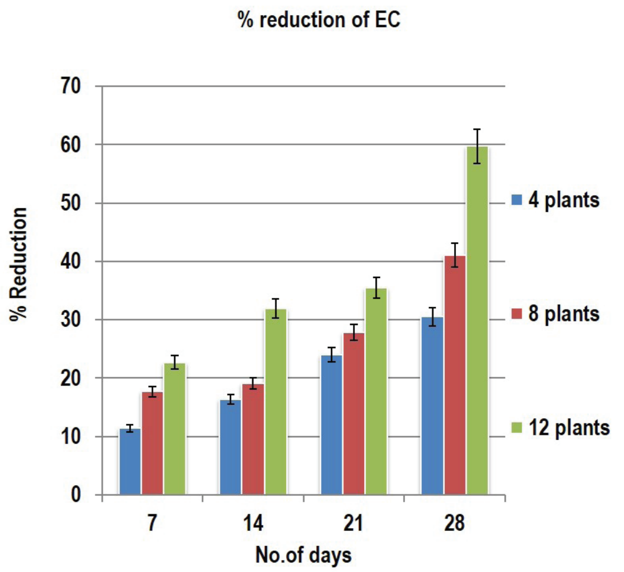
Fig.4: Percentage reduction of COD and BOD_5 with time

Vetiver plants support the BOD_5 and COD level reduction processes by availing atmospheric oxygen in their submerged stems, roots and tubers, which is then utilized by the microbial decomposers attached to them below the level of the water to digest the organic matter in wastewater. The analysis of variance showed that the effect of Vetiver on reduction of BOD_5 concentration was statistically significant (p=0.007) over control (without vetiver) treatment. The effect of Vetiver treatment on the reduction in BOD_5 concentration (19 mg/L) was statistically significant over control (75 mg/L) treatment. The analysis of variance also showed effectiveness of Vetiver in COD reduction was statistically significant (p=0.006).

Treating wastewater with Vetiver resulted in a statistically significant reduction in COD concentration (1440mg/L-54mg/L). From this result, it is distinctly clear that the effectiveness of wastewater treating potential of Vetiver in terms of organic matter removal (BOD_5 and COD) as compared to control. BOD_5 and COD results obtained in the present study was higher than the removal results obtained in the field from piggery wastewater had reported 35.8% BOD_5 as well as 64% COD removal after four weeks treatment (Liao et al, 2003). The efficiency of organic matter removal depends on the strength of wastewater and the treatment time (Ronnachai et al., 2007). Therefore, the pragmatic incongruity in the organic matter removal efficiency with different literatures might be due to difference in concentration of wastewater, treatment time and method of Vetiver application.

On average, the effectiveness of Vetiver for pollutant treatment in the present experiment was not so distinct in the first few weeks'. This was probably due to the relatively smaller biomass and the relatively poorer adaptation to the wastewater environment. From these results, it is seen that Vetiver has great potential in treating waste water. After four weeks hydroponic treatment, the BOD5, and COD met the maximum discharge limit set by NEMA.

The results clearly show that the uptake of concentrations of TDS and EC increased with increase in quantity of biomass. TDS percentage reduction was for 76%, 83.1% and 89.3%, 4 plants, 8 plants and 12 plants respectively for duration of four weeks while that of EC 60.8%, 72.7% and 86.4% for 4 plants, 8 plants and 12 plants respectively for twenty eight days (figure 5). The electrical conductivity values of Vetiver sets were lower than the



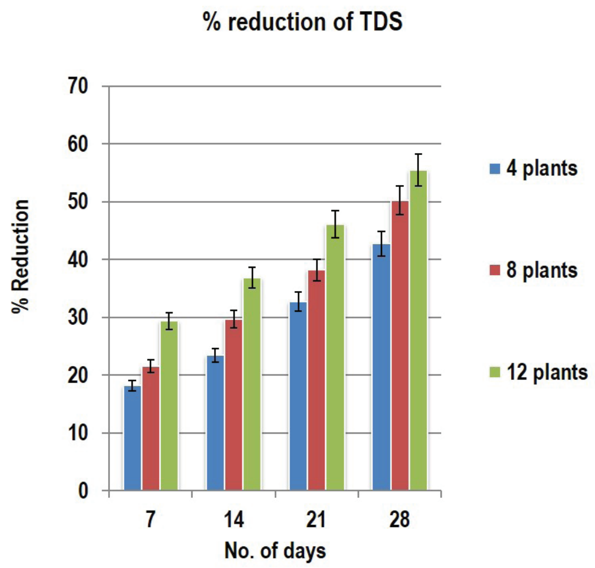
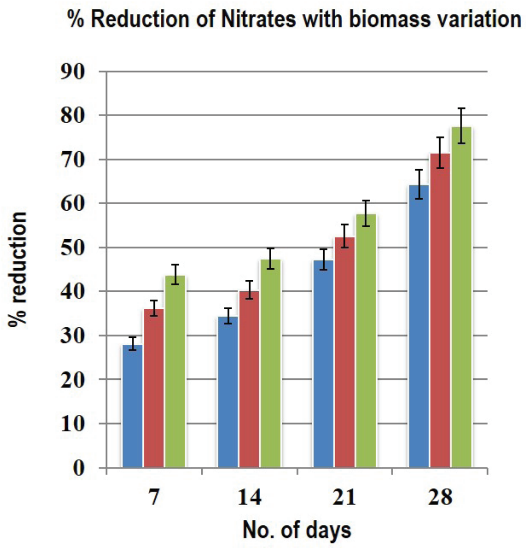


Fig.5: Percentage reductions of EC and TDS with biomass variation

control sets in all hydroponic treatment because Vetiver absorbed most of the ions responsible for conductivity. The analysis of variance shows that the effectiveness of Vetiver in removal of TDS were statistically significant for 4 plants treatment ($p=0.018$), 8 plants treatment ($p=0.002$) and 12 plants treatment ($p=0.005$) hence indicating the potential use of Vetiver grass in the treatment of effluent wastewater. Reduction of total dissolved solids in this study might be due to the variation of wastewater concentration, configuration of hydroponic vetiver set-up (container as growing medium), temperature, treatment time, quantity of vetiver applied and hydraulic retention time (HRT) used in this study could be another factor (Bedewi, 2010).

Generally, there was reduction of both nitrates and TN in all treatments. Nitrates reduced by 91.2%, 94.9% and 97.2% for 4 plants, 8 plants and 12 plants respectively in four weeks treatment while TN concentrations reduced by 70%, 79.2% and 90.1% for 4 plants, 8 plants and 12 plants respectively in four weeks of treatment (figure 6). The highest reduction of nitrates and TN was evident in the 12 plants treatment.



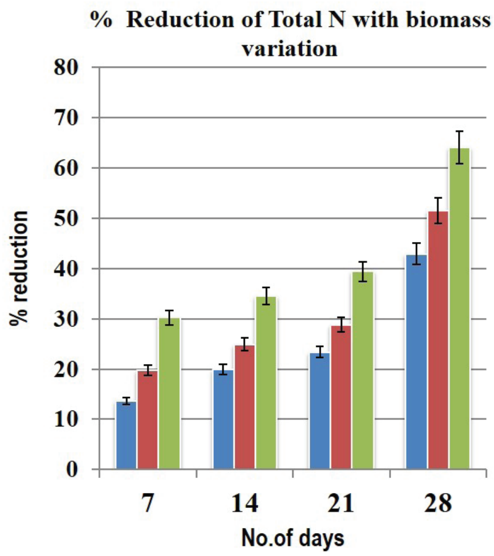


Fig.6: Percentage reductions of TN and nitrates with biomass variation

The optimum pH and temperature condition for nitrification process is in the range of 6.5 to 8.6 and 20 °C to 30 °C respectively (Grunditz & Dalhammar, 2001).The reduction of nitrogen and nitrates in the wastewater might have occurred due to microbial activities; nitrification and denitrification, evaporation and plant and bacterial uptake phenomenon. In addition, the accumulation of oxygen around the roots leads to more nitrification making the nitrogen and nitrate removal more probable (Dhanya & Jaya, 2013).

The result of the analysis of variance revealed that the potential of Vetiver in reduction of TN was significant at p=0.018 for 4 plants, p=0.002 for 8 plants and 0.012 for 12 plants. Results obtained for TN and nitrates were higher than those reported earlier, 43.85% and 76.2% reduction of TN and nitrates were reported at a HRT of twenty eight days and 3 plants of Vetiver planted hydroponically (Danh et al., 2006). Generally, the results strongly indicate that there was a linear correlation between quantity of Vetiver plants used and uptake of pollutants i.e. 12 plants >8 plants >4 plants.

CONCLUSION AND RECOMMENDATIONS

The study shows that vetiver was effective in wastewater treatment since all the units that contained vetiver plants performed better than the plant controls. Vetiver grass growing under hydroponic with no supporting medium, can effectively remove organic matter and nutrients from municipal wastewater. The potential of Vetiver grass after four weeks hydroponic treatment was found to be efficient for the reduction of pH, chemical oxygen demand, biological oxygen demand, total nitrogen, nitrates and electrical conductivity from wastewater. There was a linear correlation of biomass with reduction of pollutants. From the results obtained and the challenges faced during the experiment period, the following recommendations are made:-

1. Vetiver is effective in reduction of BOD, COD and nutrients to the required levels for disposal of wastewater to the environment, hence can be used at Kipevu WWTP.
2. Vetiver can be introduced in the two aeration tanks to reduce electricity costs at Kipevu WWTP.
3. Further research should be conducted to monitor pollutant removal in the aeration tank with a given amount of Vetiver biomass per the volume of wastewater at the retention time currently in practice.
4. Further research regarding amounts of nutrient and heavy metals accumulation in roots and shoots of Vetiver should be done. And how the toxic contaminants can be converted into less harmful sub-

stances to avoid transfer of pollution from one source to another.

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