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Treatment of flower farm wastewater effluents using constructed wetlands in lake Naivasha, Kenya

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Abstract

Lake Naivasha, Kenya, is a fresh water lake currently experiencing severe environmental problems as result of pollution from agricultural effluents and urban water surface runoff, uncontrolled water abstraction, improper land use practices in the catchment area and proliferation of wetlands' invasive species. These problems are exacerbated and compounded by changes in climate and inadequate conservation interventions. To deal with the pollution problem, flower farms around the lake have adopted constructed wetland technologies to treat their wastes prior to release into the lake's ecosystem. In this study, we examined the efficiency of one of the largest and oldest constructed wetland, the Kingfisher constructed wetland, owned by Home Grown Ltd. The study was conducted between October 2009 and March 2010. Measurements of water quality parameters were carried out at 9 sampling stations along the constructed wetland system from inlet to outlet. The results showed that water quality significantly improved from inlet to the outlet, with conductivity declining from 722 μScm^{-1} to 514 μScm^{-1} while TDS declined from 569 to 186 mgl^{-1}. Other water quality parameters such as total suspended solids (TSS), BOD, COD, total nitrogen and total phosphorous similarly declined significantly ($P < 0.05$) from inlet to outlet. Heavy metals generally occurred in low concentrations at the inlet, but still declined in their concentrations though not significantly. Results show that constructed wetlands are highly efficient in wastewater effluent treatment and can be used in amelioration of point sources of pollution into inland water bodies.

Keywords: Water pollution; Flower farm effluents; Lake Naivasha; Wetlands

Introduction

Constructed wetlands (CWs) are engineered systems that have been designed and constructed to utilize natural processes involving wetland vegetation, soils and their associated microbial assemblages to assist in treating wastewater (Vymazal, 2001). Additionally, they are now recognized as ecologically sustainable option for water pollution control and are designed to take advantage of many of the same processes that occur in natural wetlands but do so within a more controlled environment. They are thus gaining popularity all over the world because unlike conventional treatment systems, they are cost-effective and reliable. According to Olson (1993), CWs are simple self-regulating and self-maintaining systems which do not rely on complex technology. In addition to pollutant removal functions, CWs have other ecological functions, such as creating habitats for biodiversity and increasing the aesthetics of the site.

Many studies reveal that constructed wetlands are efficient in removal of various pollutants and nutrients (e.g. Kaseva, 2004; Solano, *et al.,* 2004; Kern & Idler, 1999). Rowe (1995) noted that CWs achieve high removal rates for biochemical oxygen demand (BOD), total suspended solids (TSS), Nitrogen and heavy metals. Also Cooper and Findlater (1990) identified the key regulatory parameters in water pollution control in CW as TSS, BOD, Nitrogen and Phosphorus. Another important factor that influences the treatment performance of a CW is the inlet hydraulic loading rate (HLR) (Kadlec & Knight, 1996).

The first scientific research studies of constructed wetland for wastewater treatments were carried out in Germany in 1953 at the Max Planck Institute by Kathe Seidel (Vymazal, 2005). In the study, the researcher determined the ability of aquatic plants to absorb and breakdown pollutants. Since then constructed wetlands for wastewater treatment have been widely adopted in developed countries (Campbell and Ogden, 1999). In Africa, however, constructed wetlands are a relatively new concept although they are better suited to the tropics than to the temperate regions where during winter, their efficiency is greatly reduced (Linsley, 1992). In Kenya, a few working privately owned CWs exists, which mainly treat wastewater from various sources. The first such wetland is the Splash Wetland in Nairobi, which was constructed in 1994 by consultant Dee Raymer for the purpose of recycling wastewater from two restaurants (Nzengy'a & Wishitemi, 2001) and further modified with a new GBH (Gravel Bed Hydroponics section) in 2000. Later similar wetlands were constructed in Naivasha area by commercial flower farmers to treat wastewater effluents emanating from the flower farms before discharge into the environment.

Despite the increasing application of constructed wetlands in flower farm wastewater treatment around Lake Naivasha, data on their efficiency remains scanty. Despite the paucity of information the technology remains taunted as the solution to the pollution problems currently facing Lake Naivasha. There is therefore need to intensively evaluate the efficiency of the constructed wetlands in treating the flower farm waste water effluents in order to enable Kenya publish national guidelines like in other developed countries. This study therefore aimed at assessing the efficiency of a full scale constructed wetland treating wastewater from a commercial flower

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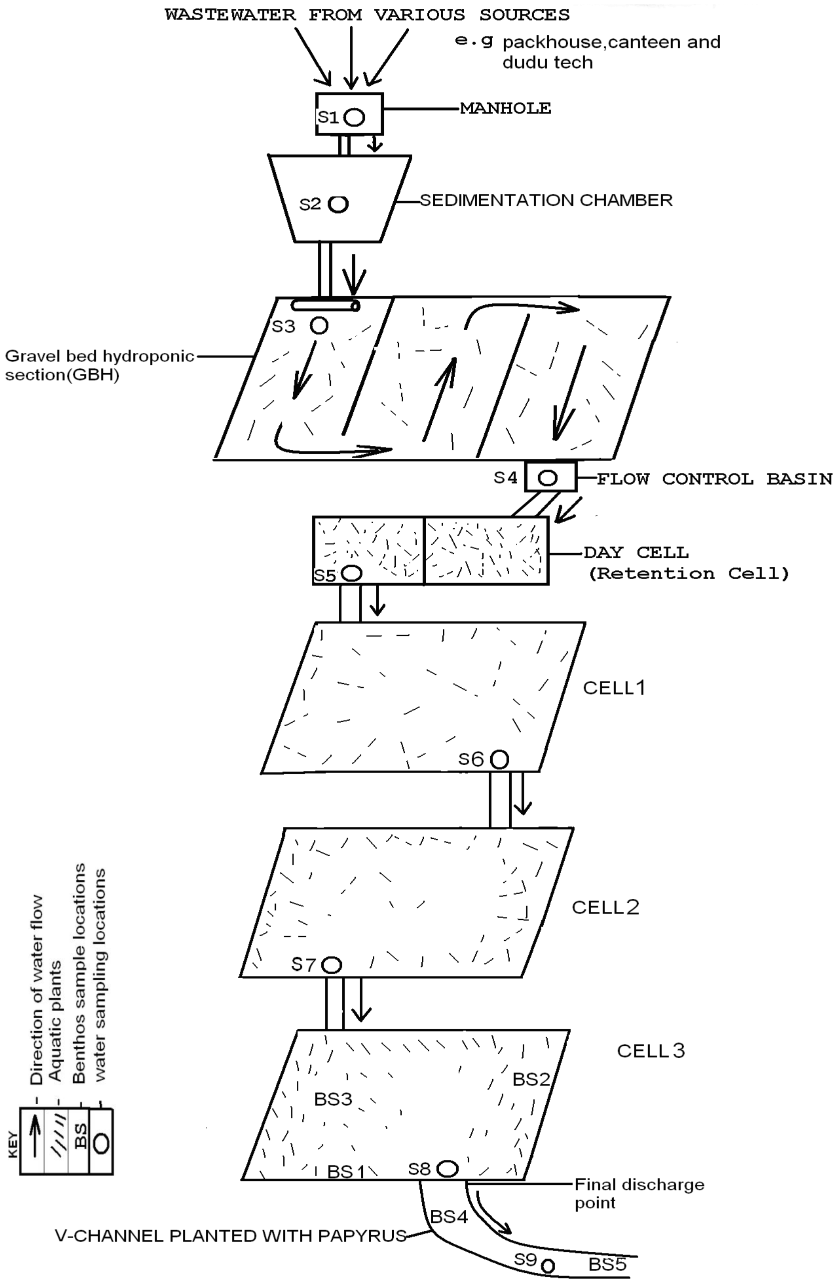
Fig. 1. S1-inlet, S2-sedimentation chamber, S3-inlet GBH, S4-outlet GBH, S5-outlet day cell, S6, S7, and S8 are outlets cell 1, 2 and 3 respectively and S9-v-channel.



farm (the Homegrown Kingfisher flower farm) near the shores of Lake Naivasha.

Study area

Lake Naivasha is situated 100 km Northwest of Nairobi at an altitude of 1890m above sea level, between latitudes 36°15′- 36° 25′ E and 0° 37′- 0° 50′ S. The area is generally semi-arid, receiving an average rainfall of approximately 700mm per annum. Rainfall distribution is bi-modal, with long rains occurring from April to June and the short rains from October to December. The lake is an important biodiversity hot spot and has been designated a Ramsar site to promote conservation of the large number of wildlife and bird species. The lake however, faces major challenges from excessive water abstraction, over fishing, improper agricultural practices, catchments degradation, environmental pollution, invasive species and effects of climate change. The lake is surrounded by a large number of flower farms, which have been blamed for excessive pollution of the Lake ecosystem. A number of farms, however, have adopted constructed wetland technologies to treat their waste water effluents prior to release in to the lake ecosystem. A good example is the Kingfisher constructed wetland in Naivasha. The Kingfisher constructed wetland was constructed in the year 2005 at approximately $40,000 and was designed to receive approximately 45m^3 of wastewater per day from pack houses (where cut flowers are stored, graded and packaged for export), Dudu Tech houses (where production of bio-control agents for Integrated Pest Management on flowers take place), staff canteen, laundry, equipments and spray gears washings and septic water from wash rooms. The Kingfisher wetland is a combined (hybrid) system of a subsurface flow system known as gravel bed hydroponics (GBH) section and a surface flow system with three sequential treatment cells (Fig.1).

The wetland has multiple vegetation species; the dominant vegetation in the GBH includes *Canna sp., Hydrocotyle sp.* and *Cyperus sp.* The day cell is covered by *Hydrocotyle umbellate* on the water surface and *Cyperus alterufolia* around the perimeter. The surface cells are dominated by the floating *Pistia sp.* and multiple macropytes around the perimeter including sedges, giant reeds, canna and other decorative plants which enhance the system attractiveness and visual appeal. In the v-channel the dominant species is *Cyperus papyrus*.

Materials and methods

Samples were collected fortnightly for a period of six months from October, 2009 to March, 2010. Nine sample locations (S1-S9) were selected and sampled systematically from inlet, to the outflow. The final sampling location (S9) was established 35m from the final discharge point in the V-channel (Fig.1). Samples were

Table 1. Treatment performance and removal efficiency as percentage of kingfisher flower farm constructed wetland.

Parameter	Inflow (mg/l)	Outflow (mg/l)	Efficiency %	*Kenyan Standards (mg/l)
Total suspended solids (TSS)	233	23	90.1	30
Total dissolved solutes (TDS)	357	260	27.1	1200
Biological oxygen demand (BOD)	138	72	47.8	30
Chemical oxygen demand (COD)	569	186	67.3	50
Total nitrogen (TN)	5.1	2.0	60.7	-
Total phosphorous (TP)	5.1	2.6	52.7	-
Lead (Pb)	0.04	0.03	25.0	0.01
Copper (Cu)	0.06	0.03	50.0	1.0
Manganese (Mn)	0.26	0.07	73.1	10

** Kenyan Standards for effluent discharge into the environment (extracted from the Environmental Management and Co-ordination, (water quality) Regulations 2006.*

Table 2. Results of Tukey's test for the measured variables

Site	Sites showing significance difference							
	Temp	pH	C	TDS	BOD	TN	TP	TSS
1	4,6,9	none	8,9	8,9	5 - 9	8,9	none	4,7,8,9
2	4,9	2,8,9	none	none	5 - 9	8,9	9	6 - 9
3	4,9	8,9	none	none	5 - 9	9	8.9	6 - 9
4	1,2,3,5	8	7,8,9	7,8,9	5-9	8,9	8,9	1,5,6
5	4,9	none	7,8,9	7,8,9	All	8,9	8,9	4,7,8,9
6	1,9	8	none	none	1-3, 5-9	8,9	9	2,3,4,7,8,9
7	9	none	4,5	4,5	1 - 6	none	none	1-3,5,6,8
8	9	2,3,6	1,4,5	1,4,5	1 - 6	1,2,4-6	3,4,5	1-3,5,6,8
9	1 - 8	2,3	1,4,5	1,4,5	1 - 6	1 - 6	2 - 6	1-3,5,6,8

collected between 08.30 and 10.30 hours using 500ml acid sterilized bottles after rinsing at least thrice with the site water. At each site, duplicate water samples were collected and transported to Nakuru Water Quality Testing Laboratory in ice-cooled boxes at least within two hours after sampling. In total, 90 water samples were analyzed, with 10 measurements for each variable made per sample location during the study period. In the laboratory, water samples were analyzed for changes in nutrient levels (nitrates and total phosphates) through the system using methods described in APHA (2004). In addition, changes in concentrations of selected heavy metals (copper, lead and manganese) were also measured. Total nitrogen concentrations were determined by colorimetry following the persulfate digestion procedure while total phosphorus was determined by ascorbic acid method. Lead (Pb), Copper (Cu) and Manganese (Mn) were analyzed using an atomic absorption spectrophotometer model S2AA system set to absorbance mode. Additionally biological oxygen demand (BOD) and chemical oxygen demand (COD) were assessed by incubation and titrimetric methods, respectively. Temperature, pH, conductivity and total dissolved solids were measured *in situ* using a multi-probe meter HI 991300 model. Total suspended solids were determined by standard procedure using GF/C filter paper (APHA, 2004). Chemical oxygen demand (COD) was determined according to closed reflux titrimetric method. Biological oxygen demand (BOD) was determined by incubation method whereby the sample is incubated for 5 days at 20^0C in presence of acclimated biological system (Table 1).

The data was analyzed using the SPSS 11.5 statistical software package. One way ANOVA was used to test the overall variation and differences in water quality status from the inlet to the outlet. Further Tukey test was applied to show significant differences between sites (Table 2). All statistical tests considered significant at P<0.05 (95% confidence). The overall levels of efficiency of the wetland were calculated based on the comparison of inlet mean concentration versus outlet mean concentration.

Result

Water temperature

Water temperature decreased significantly ($F_{8,81}$=12.78, P<0.05) from 23.1±0.35^{O}C at the inlet to 18.3±0.38^{O}C at the outlet (Fig. 2). Tukey's test (Table 2) revealed significant differences in water temperature between the vegetated gravel bed hydroponics (S3) and v-channel S9. Comparison of the wastewater temperature at the inlet and outlet during the study period (Fig. 3) showed that the temperature remained lower at the outlet than the inlet. As expected water temperature however, increased slightly at the outlet in the dry month of January.

pH

Mean pH changed significantly ($F_{8,81}$=5.39, P<0.05) from 6.81±0.17 at the inlet to 6.65±0.10 at the outlet (Fig. 4). Specifically pH increased in the GBH (S3-S4) then decreased in the day cell (S5) In the surface cells (S6-S7), pH again increased significantly (Tukey's test) reaching a high of 7.4, after which it declined at the outlet to a low of 6.65.. At the outlet pH changes remained relatively stable (Fig. 5) throughout the study period as compared to the inlet where greater variation occurred.

Conductivity changes

A great significant reduction in conductivity ($F_{8,81}$=6.38, P<0.05) was observed as wastewater flowed through the wetland system from a high of 722±631.86 µScm^{-1} to a low of 514±14.75 µScm^{-1} (Fig. 6). But despite the significant overall decline, a notable increase in conductivity occurred in the GBH and day cell (S3-S5). In the surface cells, conductivity decreased abruptly all the way to the v-channel (S6-S9). Comparison of conductivity variations between the inlet and outlet during the study period showed that while conductivity varied greatly at the

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Fig. 2. Spatial variation in water temperature through the Kingfisher constructed wetland system in Naivasha Kenya. S1-S9 are sampling sites from inlet to outlet through the different cells.

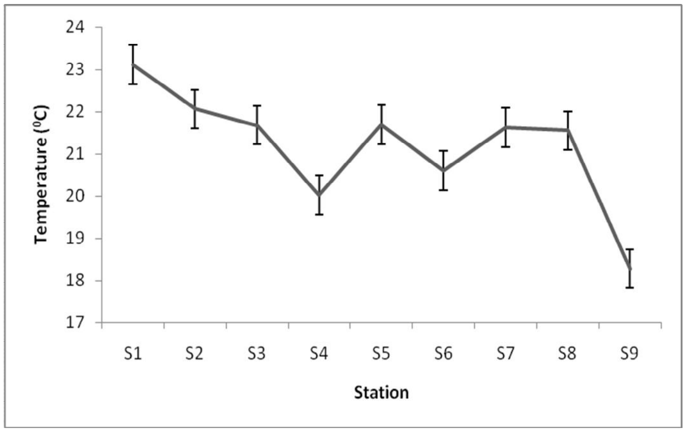

Fig. 3.Temporal variation in water temperature at the inlet and outlet of the Kingfisher flower farm constructed wetland system in Naivasha, Kenya.

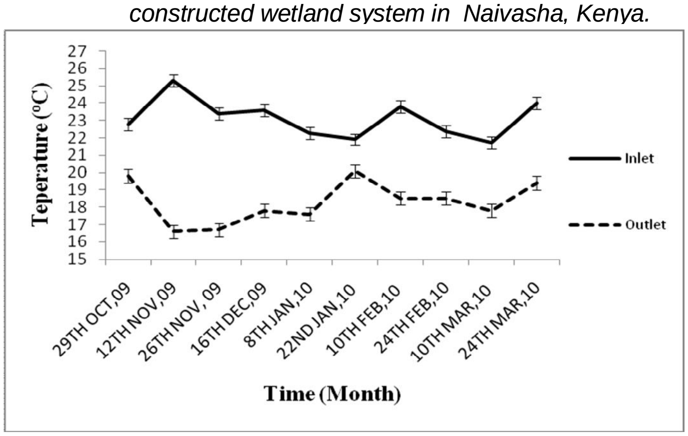

Fig. 4. Spatial variation in pH through the Kingfisher constructed wetland system in Naivasha, Kenya. S1-S9 are sampling sites from inlet to outlet through the different cells.

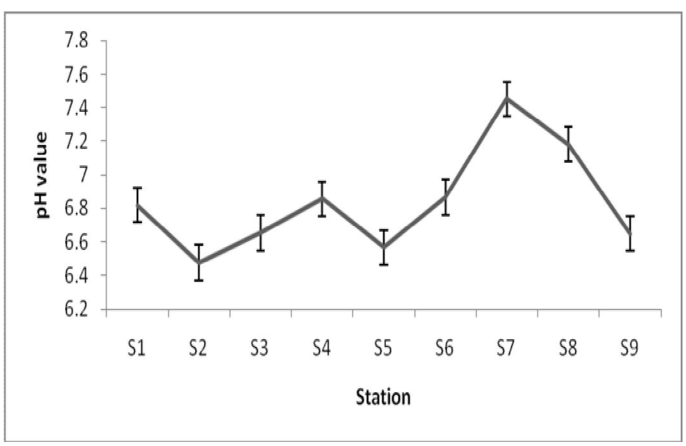

Fig. 5. Temporal variation in pH at the inlet and outlet of the Kingfisher flower farm constructed wetland system in Naivasha, Kenya.

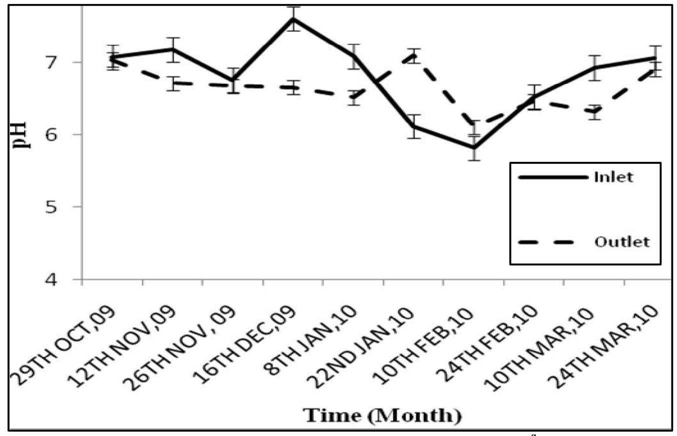

Fig. 6. Spatial variation in conductivity (µScm^{-1}) through the Kingfisher constructed wetland system in Naivasha, Kenya. S1-S9 are sampling sites from inlet to outlet through the different cells.

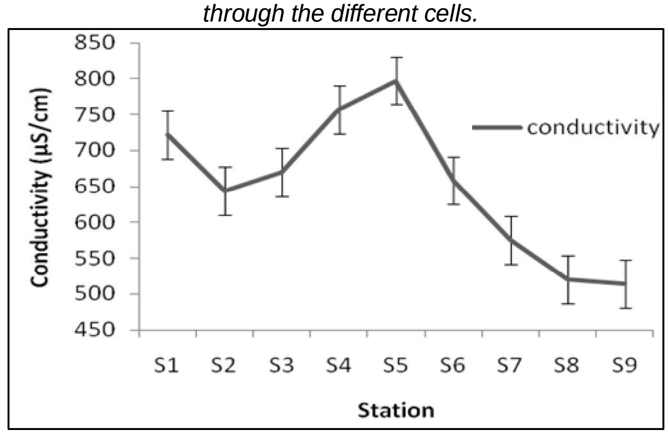

Fig. 7. Temporal variation in conductivity (µScm^{-1}) at the inlet and outlet of the Kingfisher flower farm constructed wetland system in Naivasha, Kenya.

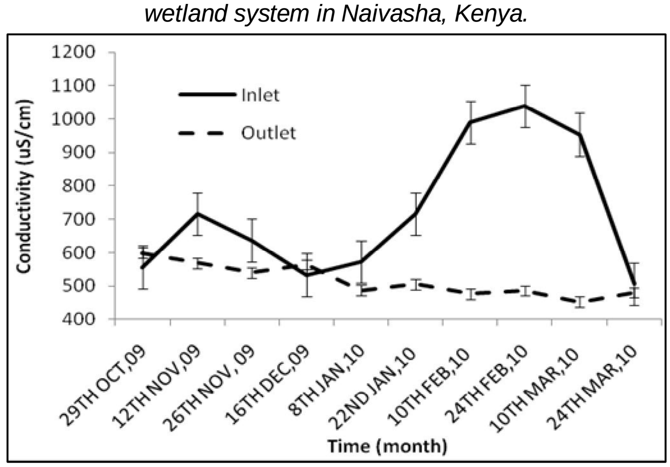

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Fig. 8 Spatial variation in TDS (mg/l) through the Kingfisher constructed wetland system in Naivasha, Kenya. S1-S9 are sampling sites from inlet to outlet through the different cells.

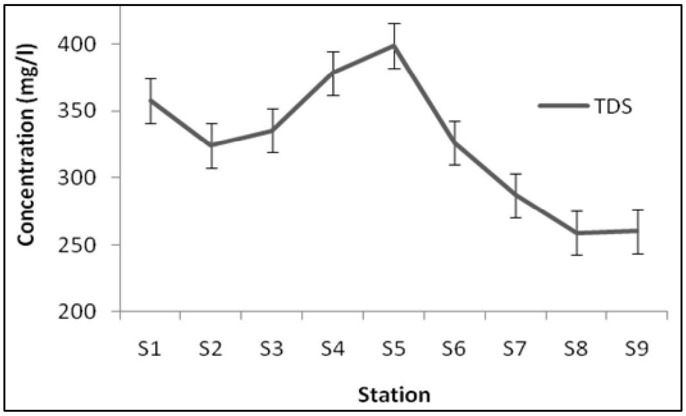

Fig. 9. Temporal variation in TDS (mg/l) at the inlet and outlet of the Kingfisher flower farm constructed wetland system in Lake Naivasha, Kenya.

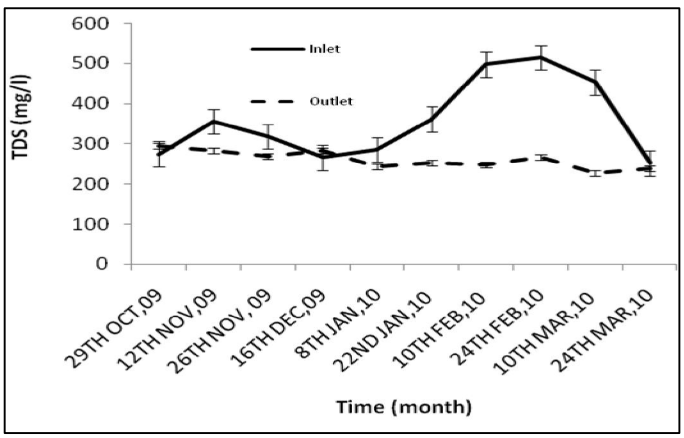

Fig. 10. Spatial variation in TSS (mg/l) through the Kingfisher constructed wetland system in Naivasha, Kenya. S1-S9 are sampling sites from inlet to outlet through the different cells.

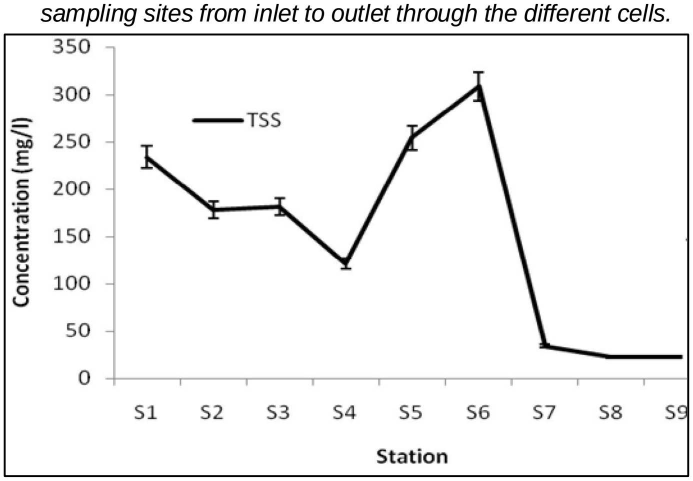

Fig. 11.Temporal variation in TSS (mg/l) at the inlet and outlet of the Kingfisher flower farm constructed wetland system inLake Naivasha, Kenya.

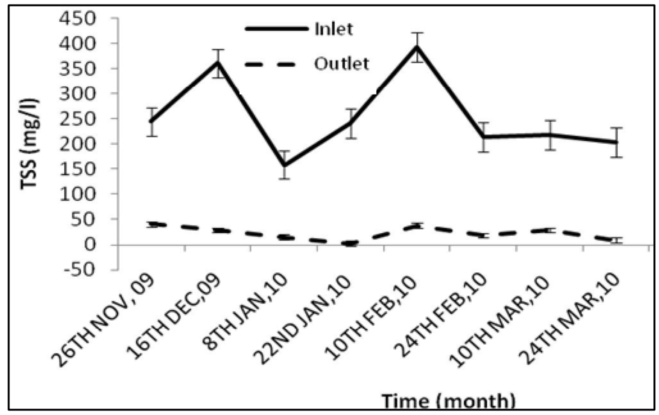

Fig. 12. Spatial variation in BOD (mg/l) through the Kingfisher constructed wetland system in Naivasha, Kenya. S1-S9 are sampling sites from inlet to outlet through the different cells.

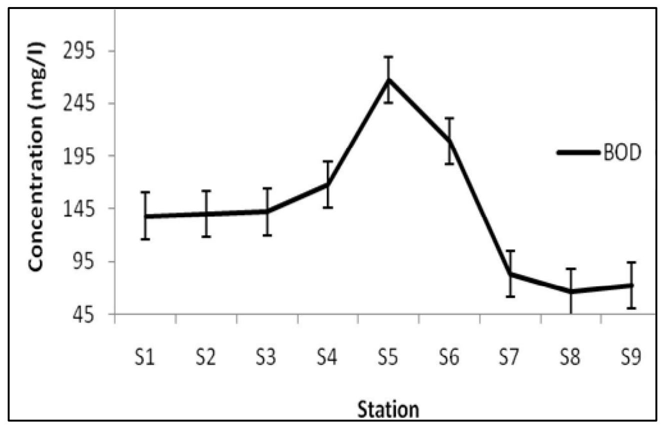

Fig. 13. Temporal variation in BOD (mg/l) at the inlet and outlet of the Kingfisher flower farm constructed wetland system in Lake Naivasha, Kenya.

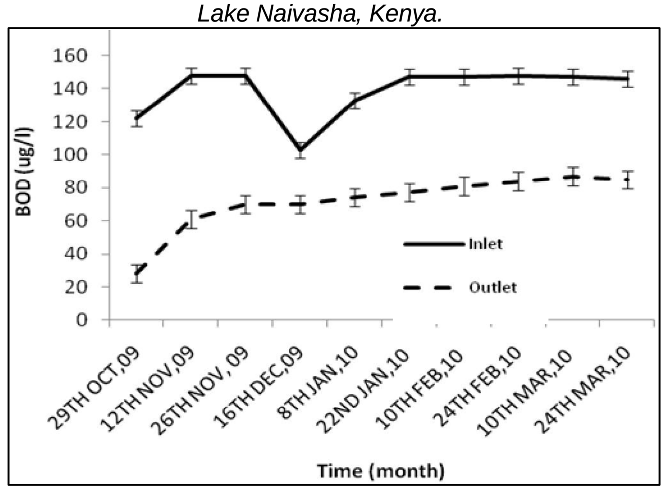

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Fig. 14. Spatial variation in COD (mg/l) through the Kingfisher constructed wetland system in Naivasha, Kenya. S1-S9 are sampling sites from inlet to outlet through the different cells.

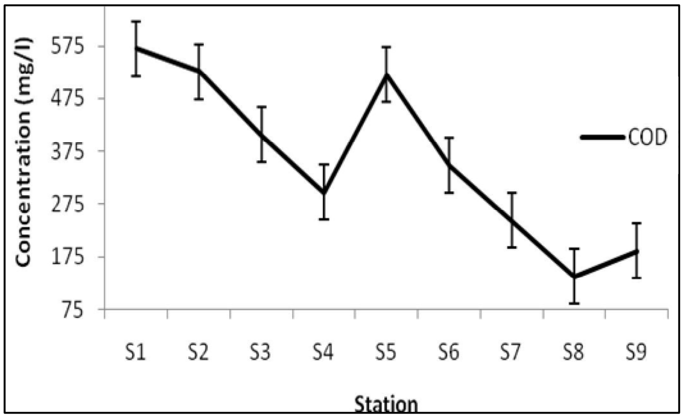


Fig. 15. Temporal variation in COD (mg/l) at the inlet and outlet of the Kingfisher flower farm constructed wetland system in Naivasha, Kenya.

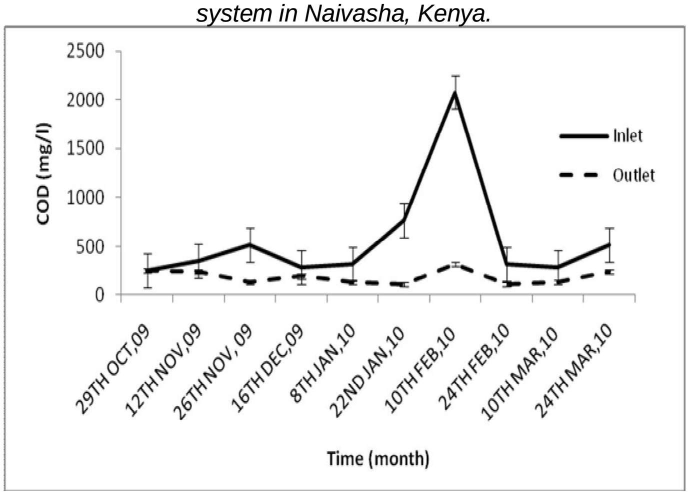


Fig. 16. Spatial variation in total nitrogen (mg/l) through the Kingfisher constructed wetland system in Naivasha, Kenya. S1-S9 are sampling sites from inlet to outlet through the different cells

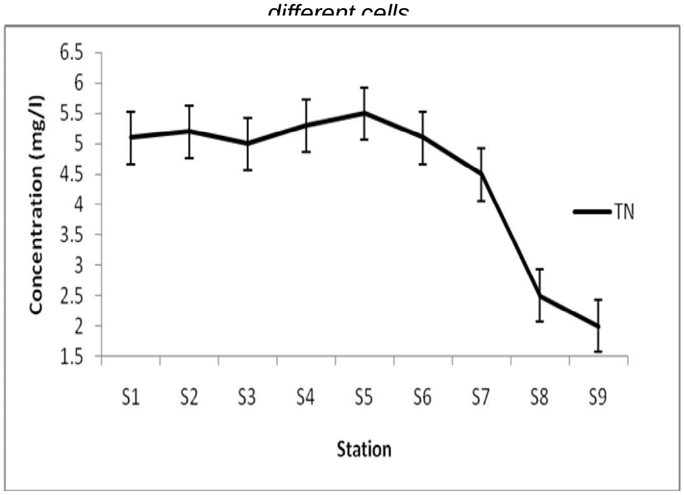


Fig. 17. Temporal variation in total nitrogen (mg/l) at the inlet and outlet of the Kingfisher flower farm constructed wetland system in Naivasha Kenya.

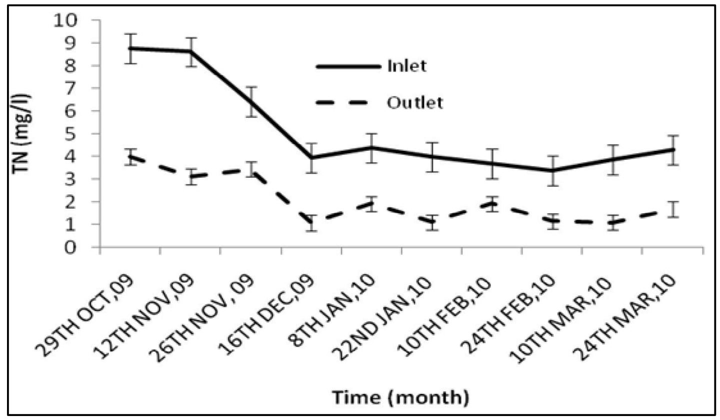


Fig. 18. Spatial variation in total phosphorous (mg/l) through the Kingfisher constructed wetland system in Naivasha, Kenya. S1-S9 are sampling sites from inlet to outlet through the different cells.

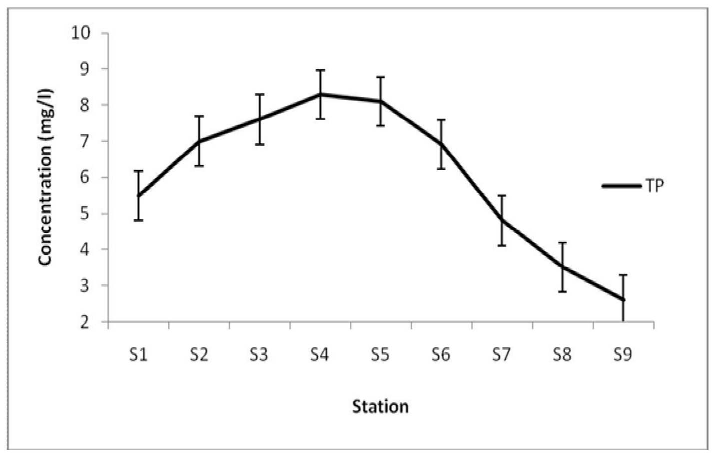
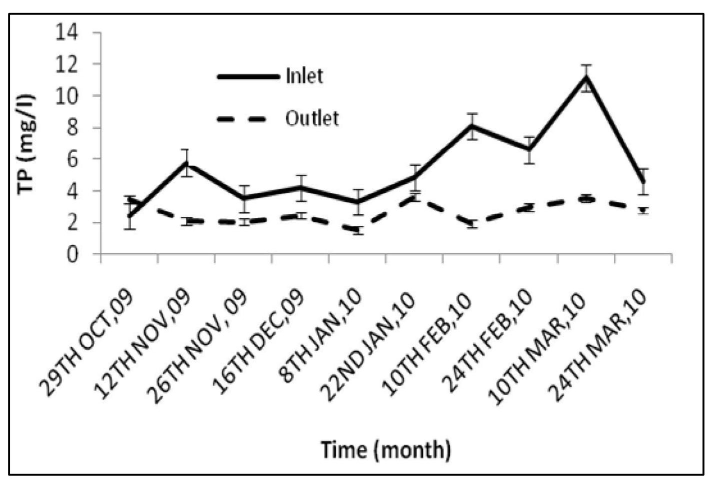


Fig. 19. Temporal variation in total phosphorous (TP) at the inlet and outlet of the Kingfisher flower farm constructed wetland system in Naivasha, Kenya.



inlet, it remained low and almost constant at the outlet (Fig.7). The outlet concentration remained low throughout the study period despite high concentration at the inlet in February .

Total dissolved solids (TDS)

Like conductivity, TDS decreased significantly ($F_{8,81}$=6.45, P<0.05) from inlet (357±30.92 mgl^{-1}) to the outlet (260±7.06 mgl^{-1}; Fig. 8). However, a significant higher values were observed at the vegetated gravel bed and day cell (S3-S5) when compared with the free surface cells (S6-S8). A comparison of changes in TDS concentration at the inlet and outlet through the study period showed that concentration remained low and almost constant at the outlet (Fig. 9) but showing great variation at the inlet. The highest TDS was reported in February, 2010.

Total suspended solids (TSS)

The mean concentration of total suspended solids decreased significantly ($F_{8,81}$=17.79, P<0.05) from 233±26.47 mgl^{-1} at the inlet to 23±3.94mgl^{-1} at the outlet (Fig. 10). Despite the decline, TSS highly increased in site S4-S6 In site S6-S8 however, the concentration of TSS decreased significantly indicating high sedimentation in the free surface cells. Inflow values of TSS ranged between 137 mg/l and 393 mg/l while the outflow values ranged between 3 mgl^{-1} and 41 mgl^{-1}.Temporal variation showed that the amount of total suspended solids varied from time to time but these variations did not affect the quality of the water at the outflow (Fig. 11). At the outlet the TSS concentration remained relatively low throughout the study period.

Biochemical oxygen demand (BOD)

Changes in BOD as the wastewater flowed through the wetland system (Fig. 12) closely mirrored that of conductivity (Fig. 6), TDS (Fig. 8) and TSS (Fig. 10) and showed high accumulation of pollutants in the day cell (S5). Overall the mean BOD significantly declined ($F_{8,81}$=33.64, P<0.05) from a high of 138±15.09 mgl^{-1} at the inlet to 72±5.49 mgl^{-1} at the outlet. Like other parameters, BOD increased at the day cell (S5) reaching a high of 267±15.09mgl^{-1} and then decreased continually to the v-channel. Comparison of BOD variations through time at the inlet and outlet (Fig. 13) showed the BOD to be consistently lower than the inlet. This result corresponds to the trends observed with conductivity, TDS and TSS.

Chemical oxygen demand (COD)

The mean concentration for COD varied significantly ($F_{8,81}$=2.32, P<0.05) along the wetland system from a high of 569±175 mgl^{-1} to 186±62 mgl^{-1} at the outlet (Fig. 14). However, unlike BOD, the COD concentration decreased significantly at the sedimentation chamber and GBH, after which it rose significantly in the day cell (Tukey's test) to a high of 519±114 mgl^{-1}. But like all other parameters, its concentration decreased steadily in the surface cells. Comparison of COD variations between the inlet and outlet through time showed that COD remained relatively stable at the inlet except in the month of February when a sharp increase was observed (Fig. 15). COD then decreased abruptly towards the end of February 2010 and then remained low till the end of study period.

Total nitrogen (TN)

The mean concentration of TN at the outflow was significantly lower ($F_{8,81}$=5.02, P<0.05) than the inflows measuring 2.0±0.34 mgl^{-1} and 5.1±0.65 mgl^{-1}, respectively (Fig. 16). The concentration of TN initially remained relatively constant until after the retention (day) cell when the concentration declined significantly (Tukey's test). This again confirms the importance of the surface cells in the uptake of wastewater effluent constituents. Variation through time showed higher concentration of TN in both inflow and outflow between October and December, 2009 and then remained constant throughout the study period (Fig. 17). However, the concentration of TN at the outlet remained relatively lower than the inlet throughout the study period.

Total phosphorus (TP)

Total phosphorus concentrations in the flower farm wastewater effluents showed a similar trend like the TN, initially increasing slightly up to the day cell when the concentration abruptly decreased from a high of 5.5±0.82 mgl^{-1} to a low of 2.6±0.24 mgl^{-1} (Fig. 18). Mean concentration of TP was significantly lower at the outflow ($F_{8,81}$=5.02, P<0.05) than the the inflow with the vegetated GBH cells having significantly higher TP concentrations than other cells (Tukey's test). Analysis of TP concentrations at the inlet and outlet through time showed the outlet consistently having lower concentration than the inlet (Fig.19). Similar to other parameters (conductivity, COD and TSS), the concentration of TP showed a steady increase through the study period till early March 2010, when the concentration decreased abruptly to a low of 2.6±0.24 mg/l. At the outlet the concentration varied from time to time but generally remained relatively low throughout the study period.

Lead (Pb)

The mean concentration of lead was unexpectedly low in the flower farm wastewater effluents, ranging from undetectable levels to a high of 0.15±0.13 mgl^{-1}. Mean concentrations did not vary significantly between the inflow and outflow effluents although increases were observed at sites S5 and S6 though not significant. Temporal variation did not reveal any clear trends between the inflow and outflow, although increases were detected in early January, in close association with other variables.

Copper (Cu)

Like lead, copper mean concentrations were also unexpectedly low, rarely exceeding 0.08mgl^{-1}. Mean concentrations ranged from undetectable levels to a high of 0.08±0.06 mgl^{-1} with an average concentrations 0.06±0.03mgl^{-1}. The concentrations of copper at the inflow did not differ significantly from the outflows, although a general decrease in concentration was observed. Temporal variation showed the concentration being generally lower at the outflows than inflows, with the concentration remaining near zero at the outflow throughout the study period.

Manganese (Mn)

Outflow mean concentrations for manganese were much lower than the inflow with an average value of 0.07±0.01 mgl^{-1}. The concentrations of manganese at the inflow did not differ significantly from the outflows, although a general decrease in concentration was observed. Like lead and copper, variation for manganese concentrations through time fluctuated from time to time and showed no obvious indicative trends during the study period. However, the outflow concentrations remained relatively low throughout the study period. Wastewater treatment efficiency of the constructed wetland system Pollutant removal efficiencies by the Kingfisher constructed wetland ranged from 25% to 90% (Table 1). The constructed wetland was most efficient in removal of total suspended solids (90%) flowed by manganese (73%), chemical oxygen demand (67%), total nitrogen (61%), total phosphorous (53%) and Copper ions (50%). However, the systems efficiency in reduction of BOD, TDS and lead ions was less than 50% (BOD_5 48%, TDS 27% and lead 25%).Although the parameters declined in their concentrations, some sites showed significant increase followed by significant decline as wastewater flowed through the system (Table 2)**.**

Discussion

Constructed wetlands have been developed with the goal of cleaning wastewater effluents, usually of organic matter which constitute the main polluting agent in most effluents (Cooper & Findlater, 1990). The Kingfisher constructed wetland in Naivasha showed high efficiency in wastewater treatment by significantly reducing the levels of most physical-chemical constituents, nutrients and heavy metals from the wastewater effluents. Similar studies in East Africa (Okurut, *et al.*, 1999; Nzengy'a and Wishitemi, 2001; Mashauri, *et al.*, 2002) have shown similar results suggesting that use of constructed wetlands is a viable alternative to wastewater treatment to other conventional methods. An unexpected observation was the steep increase in concentration of most parameters in the day cell (S5). This was followed by a steep decline in the surface cells (S6-S8). The increasing concentration for most parameters may indicate increased accumulation of ions and sediments at the GBH and the day cells. The decrease in Temp through the system indicates a significant cooling effect of the vegetation on the wastewater. The relatively lower temperature at the outlet during the study period further confirms the ameliorating effect of the system.PH increase in the GBH is probably due to increased algal growth at the site. The pH then decreases in the day cell (S5) as organic matter decomposition increased. At the outlet the pH remains stable during the study period indicating that constructed wetlands are quite efficient in stabilizing pH. The increase in conductivity & TDS in the GBH and day cell (S3 - S5) suggests that these sites acted as the main depositors of soluble ions. This may be attributed to microbial activity and mineralization of organic matter or release of nutrients back into the water as a result of plant decay, hence increasing dissolved ions content. Despite the increase the increase in conductivity and TDS in December through February the outlet concentration remained low and almost constant suggesting that the wetland system was efficient even at times of high input.

The sharp decline in TSS in surface cells (S6-S8) suggests that the CW system is behaving as an excellent sedimentation system. TSS removal efficiency was 90.2%, further indicating the high potential of constructed wetlands in treatment of waste water effluents. Since TSS is mainly removed by physical processes such as sedimentation and filtration, its increase in the retention pond (day cell) is as a result of high accumulation of pollutants. High removal of TSS results in high transparency of the outflow effluents. The decrease in BOD and COD suggest above average efficiency of the constructed wetland in the removal of organic wastes. The high BOD and COD in site S5 may be attributed to long stagnation and high decomposition in the day cell.

The effectiveness of the constructed wetland in waste water treatment became most visible when temporal variation in concentration of most parameters was compared. Most parameters showed wide temporal variations in their concentrations at inlet but stabilized at the outlet throughout the study period. Temporal variations of pollutants at the inlet were attributed to heightened farm activities and prevailing weather conditions. A key function of constructed wetlands is to lower the levels of nutrients in the wastewater effluents, which would otherwise result in eutrophication of the recipient water bodies. Removal of nutrients (TN and TP) is around average implying that the outflow effluent is still rich in nutrients. Coupled with high transparency, this may translate to high primary and secondary productivity. Nutrient removal by Kingfisher CW was however within the range reported by many authors although for different types of wastewater effluents (Vymazal, 2002; Mantori *et al.,* 2003; Konnerup & Brix, 2009). According to Konnerup and Brix (2009) the horizontal flow system improves water quality in terms of sediments and organics while free water surface improves in terms of organics and nutrients. This explains why various types of constructed wetlands may be combined in order to achieve higher treatment efficiency. Another unexpected result reported in this study was the low levels of the heavy metals in the wastewater effluents. The effluents were expected to be highly polluted with heavy metals owing to the high amount of pesticides used. The low quantities indicate that heavy metal pollution arising from the surrounding flower farms is not a major threat to the Lake Naivasha ecosystem. In fact the low amounts available are efficiently removed by the constructed wetland. Results from this study clearly show that the Kingfisher constructed wetland is highly efficient in pollution control wastewater effluents emanating from commercial flower farms operations. Most of the variables measured showed a significant decline in concentration from the inlet to the outlet throughout the study period although a marked increase occurred in the retention pond (day cell). This high accumulation of contaminants in the day cell raises doubt on its inclusion between the GBH and the surface cells. The constructed wetland however showed high efficiency pollution control and even with the occasional increases in concentration of effluents at the inlet, the outflow water quality status remained relatively stable throughout the study period. Infact, the wetland was able to accommodate occasional peaks in conductivity, TDS, TSS, BOD, COD, TN and TP without affecting the overall efficiency. Heavy metal pollution was insignificant. Some parameters measured (reached the prescribed standards by The Environmental Management Coordination (water quality) Regulations (2006) adopted by Kenya National Environment Management Authority (NEMA) (Table1). Although the removal efficiencies of metals are high, their occurrence in low concentrations reduces their overall importance as pollutants. During the study period, clogging of the GBH cells was observed severally due to excessive influx of effluent or accumulation of organic and inorganic solids which could have blocked the gravel bed void spaces causing reduced hydraulic permeability and hence surface flow in the GBH. This may be minimized by replacing the inlet end of the GBH with coarser gravel (with high porosity) and smaller grains in the middle and outlet. Additionally, regular removal of excess plant material and captured sediments will allow the wetland to continue to function and remove the accumulated phosphorus from the system. There is also need for a metering device to ensure there is no hydraulic overloading (the water flow does not exceeds the design capacity). This study shows that constructed wetlands are an important intervention strategy in dealing with the pollution threats of Lake Naivasha from the surrounding farmlands. Therefore, there is need to encourage other flower farms to adopt the Kingfisher constructed wetland technology to deal with their wastewater effluents. Public awareness is needed in order to raise the uptake of these technologies by many more farmers. Further, it warrants for continuous evaluation and monitoring studies covering all constructed wetlands in the area in order to ascertain that no untreated effluents flow in to Lake Naivasha.

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