Potential Impacts of Kirinya Wetland in Treating Secondary Municipal Effluent from Jinja Stabilisation Ponds

KANSIIME F.,* AND MWESIGYE P.,**

**Makerere University*
Institute of Environment & Natural Resources
P.O. Box 7062
Kampala, Uganda

*** Makerere University*
Department of Chemistry
P. O. Box 7062,
Kampala, Uganda

ABSTRACT

Kirinya West wetland is located on the Northern shores of Lake Victoria in Jinja- Uganda. The wetland receives secondary treated effluent from the stabilisation ponds owned and operated by the National Water and Sewerage Corporation. The effluent finally enters Lake Victoria at the Napoleon Gulf. In this paper, we report the baseline water quality before the bio-manipulation of the wetland and demonstrate the impact of Kirinya West wetland in treating secondary municipal effluent from the existing waste stabilisation ponds. The bio-manipulation of the wetland will entail spreading the effluent from the stabilisation ponds over the northern edges of the wetland so as to increase the treatment area of the wetland and its treatment efficiency. Bio-manipulation will increase the current treatment efficiency of the wetland, as the contact between plants and the wastewater will increase. The baseline data indicate that there was significant improvement of water quality as the wastewater flowed through the ponds (61% decrease in NH_4-N, 46.9% in PO_4P and 98% in faecal coliforms). There was a further reduction in the concentration of pollutants (80% for NH_4-N and 98% for faecal coliforms) as the wastewater flowed through the wetland before reaching Lake Victoria at the Napoleon Gulf. However, channelised flow allowed wastewater to flow at the western edge of the wetland and this is associated to the effluent from the stabilisation pond that discharge at the north–western edge of the wetland.

Keywords: Bio-manipulation, Kirinya West wetland, Lake Victoria, Wetlands, Wastewater treatment

INTRODUCTION

Lake Victoria, shared by Uganda, Kenya and Tanzania, is important because of its economic, social and aesthetic values to the people of the riparian nations. People depend on the lake for multiple uses, especially for food and drinking water. Unfortunately, the lake has undergone several ecological changes which manifest as algal blooms and water hyacinth infestation (Hecky, 1993; Kling *et al.,* 2001; Muggide, 2001) Contributors to the degradation of water quality include high nutrient concentrations (especially N&P) from the catchment (Hecky *et al.,* 1996, Mugidde, 2001) and in the biotic community, especially fish (Ogutu-Ohwayo *et al.,* 1996).

In most urban and semi-urban areas of developing countries, wastewater treatment is through conventional methods and only up to secondary level. This requires considerable input of electro-mechanical installations, energy, chemicals and skilled labour resulting in high investment and operation and maintenance costs. In the event that municipal authorities cannot meet these costs owing to financial and other restrictions, as is often the case in developing countries, the treatment plants deteriorate. This results in partially treated or untreated effluent being discharged into the surrounding environment. As a result, these technologies are not sustainable. This calls for the adoption of cheap and appropriate technology, which can exploit the local conditions such as high tropical temperatures. An example of such technology is the use of wetlands (natural and constructed) for wastewater treatment.

Despite the fact that the wetland technology for wastewater treatment is in its advanced development in Europe, little information is available in developing countries and especially in East Africa (Denny, 1997; Kansiime and Nalubega, 1999; Okurut, 2000). There is therefore need to enhance and understand technologies necessary for effective wastewater treatment using natural wetlands and its subsequent application. The Lake Victoria Environmental Management project (LVEMP), in its efforts to address the adverse ecological changes in the lake, is investigating the use of natural and constructed wetlands in the treatment of wastewater from urban centres around Lake Victoria. Most of these treatment facilities of the municipalities are now malfunctioning and, as a result, discharge partially treated wastewater into Lake Victoria.

The Integrated Tertiary Municipal Effluent Treatment Pilot Project of the LVEMP addresses the overall impact of municipal effluents on Lake Victoria.

The pilot project in Uganda was to bio-manipulate the Kirinya West wetland to optimise its capacity in providing tertiary treatment of municipal wastewater from Jinja town in Uganda. The bio-manipulation involves spreading the effluent from the last stabilisation pond (final effluent) over a large expanse of the wetland. Further manipulation will involve spreading effluent through a percolated pipe installed at the northern edges of the wetland just below and parallel to the stabilisation ponds. This will optimise the wastewater treatment efficiency of the wetland, by enhancing the contact between the wastewater and vegetation and associated microbial communities, which will further enhance the removal of nutrients and bacteriological pollutants. Ordinarily, the effluent flows into the wetland as a stream and is channelised. The effluent from the stabilisation ponds eventually flows into Lake Victoria at the Napoleon Gulf. The objective of this research was to assess the performance of Kirinya waste stabilisation ponds and the water quality in Kirinya West wetland prior the bio-manipulation of the wetland is carried out.

MATERIALS AND METHODS

The Tertiary Municipal Effluent Treatment Pilot Project is located in Kirinya West wetland in Jinja – Uganda (Figure 1). The Kirinya wetland is separated by road from Jinja town to Kirinya Prisons into Kirinya East wetland and Kirinya West wetland. Kirinya West wetland is a natural tropical wetland located on the northern shores of Lake Victoria at 00^0 24'N and 33^0 11'E at an altitude of 1175 m above sea level. The wetland is dominated by *Cyperus papyrus* and covers an area of 471,100 m^2 and has a mean depth of 2.3 m. It receives a secondary treated effluent from the stabilisation ponds of National Water and Sewerage Corporation (NWSC). These ponds serve a population of about 28,000 people (1996 estimates) and collect about 4,400 m^3 of wastewater per day, which originates from the central business district of Jinja. The wastewater is a mixture of domestic and industrial wastewater from the southern area of Jinja and more domestic sewage from Kirinya Prison and Walukuba Housing Estate.

Water quality assessment

To assess the performance of the stabilisation ponds, samples were taken from the inlet into the ponds (raw sewage) and outflow from last maturation pond (MP2). The data was collected from January 1998 to June 2001.

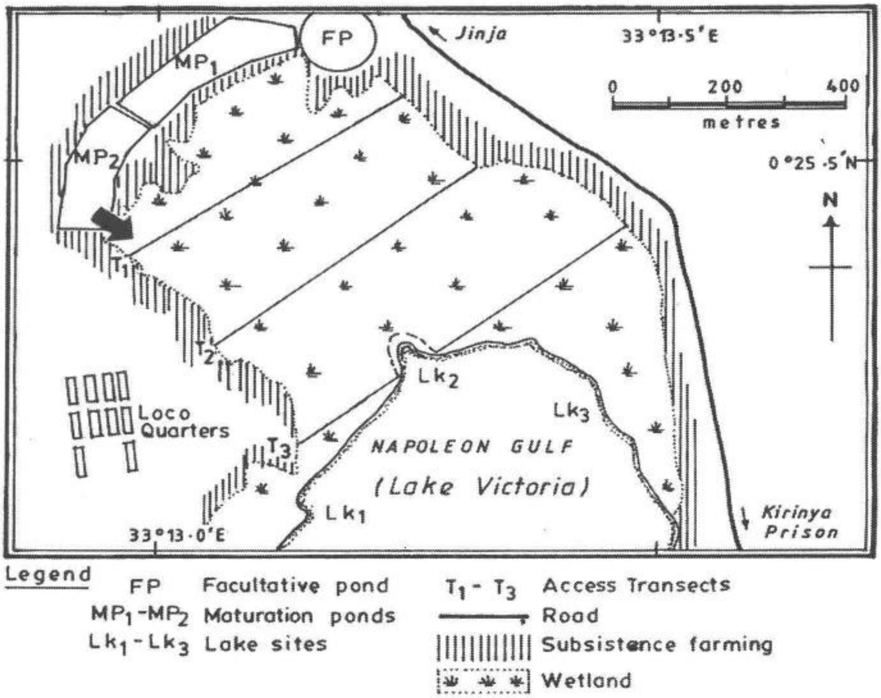

Figure 1: Map showing the location of Kirinya stabilisation ponds, the wetland and access transects

The initial phase of this study concentrated on establishing the major flow paths of the wastewater from the stabilisation ponds, as it flows through Kirinya West wetland. To trace/assess the wastewater flow patterns in the wetland; electrical conductivity (EC) was used as a tracer. This is because conductivity of the wastewater is relatively higher than that of Lake Victoria, where the wastewater from the stabilisation ponds finally discharge. The lake water has a background conductivity of about 90 to 100 μS/cm whereas the wastewater from the ponds was variable and in the range of 700 to 1500 μS/cm. This allows tracing to a certain extent, the flow of the wastewater in the wetland into the lake. The high conductivity was due to wastewater from the ponds. Conductivity in the wetland was measured in the water column and along three access transects (T1–T3) running through the wetland (Figure 1) and samples sampled at intervals of 25m.

The EC measurements were made in the water column beneath the wetland plant roots and rhizomes (the mat). To extract a sample, an auger was used to create a hole where a plastic tube was connected to a portable pump and inserted to pump water out into a 1 litre plastic bottle, in which the Wissenschaftlich-Technische Werkstätten (WTW) portable probes were placed. The bottle, on filling, was allowed to overflow until meter readings had stabilised and thereafter recorded. Electrical conductivity and also temperature and pH were measured in the field using WTW microprocessor probes and meters, LF 96 and pH90 models respectively. Calibration of the meters was done according to the manufacturer's instructions.

After establishing the flow patterns of the wastewater in Kirinya West wetland, samples were taken for laboratory analysis (of ammonium-nitrogen, total nitrogen, reactive phosphorus, total phosphorus and faecal coliforms), in order to establish the water quality in the wetland. Samples were taken at 25 m, 100 m and thereafter after every 100 m along each transect. In addition, conductivity, temperature and pH of the samples were also measured *in situ*. In order to establish the baseline conditions in the lake and the impact of the wastewater from the stabilisation ponds, which finally enter the lake, samples were also taken for laboratory analysis from the Napoleon Gulf, Lake Victoria.

Sampling and analyses were carried out basically according to Standards Methods for Examination of Water and Wastewater (APHA, 1992). Grab water samples were taken at a depth of 10 - 20 cm below the water surface for the samples taken from the ponds and the lake and in the water column below the mat for wetland samples. 500 - 1000 ml bottles were used for collection of physico-chemical samples for analysis. The bottles were thoroughly washed, rinsed with acid and finally with distilled water. For bacteriological analyses, samples were collected in 100 - 150 ml clean sterile glass bottles. Samples for laboratory analysis were transported in an icebox to a Wet Laboratory at Makerere University Institute of Environment and Natural Resources (MUIENR) where measurements were done.

The concentration of the heavy metals was read using Atomic Absorption Spectrophotometer, (Perkin Elmer, model). Preparation and sample analysis was as described in standards methods for examination of water and wastewater (APHA, 1992). Copper, zinc, cobalt, nickel and chromium were extracted from solid samples using wet acid digestion.

The Membrane Filtration Technique was used to detect faecal (thermotolerant) coliforms as described in Standard Methods (APHA, 1992). Lauryl sulphate broth was used as a test media for the presumptive phase and EC media for a confirmatory test. Ammonium-nitrogen was determined by Nessler's spectrophotometric method and according to Standard Methods (Apha, 1992). Total reactive phosphorus was determined by ascorbic acid spectrophotometric method and according to Standard Methods (APHA, 1992). Concentrations were read on a HACH DR 4000 spectrophotometer.

Statistical data analysis was performed using MINITAB Release 10 for Windows and included analysis of variance (ANOVA), Barlett's and Levene's test for homogeneity of variance and Tukey's multiple comparisons for differences between means. Regressional analysis was used to establish relationships between given variables.

RESULTS AND DISCUSSION

A summary of the variation of water quality as the wastewater flows into the stabilisation ponds, out into the wetland (along transects) and finally into the Napoleon Gulf in Lake Victoria is given in Table I. There is an improvement in the quality of wastewater as it flows through the wetland before it enters Napoleon Gulf.

Table 1. Variation of water quality of the influent into the ponds, in the wetland and in the Napoleon Gulf-Lake Victoria. The values are presented as mean ± SD and the values in parentheses represent the sample size. Temp and FC represent temperature and faecal coliforms respectively

	Variable					
Location	EC µS/cm	pH	Temp (^0C)	NH_4-N (mg/l)	O-PO_4 (mg/l)	FC No./100 ml
Inflow	929.5± 61.3 (72)	7.79 ± 0.09 (59)	26.75 ± 0.15 (72)	56.49± 4.33 (78)	19.44 ± 3.72 (73)	$2.22*10^8 \pm 1.18*10^8$ (63)
Outflow	771.9± 18.2 (67)	8.17 ± 0.13 (54)	26.43 ± 0.16 (69)	23.46 ± 2.23 (69)	11.45 ± 3.16 (65)	$1.02*10^5 \pm 7.16*10^6$ (59)
Transect 1	836± 18 (663)	7.07 ± 0.03 (572)	23.17 ± 0.09 (677)	12.46 ± 0.47 (436)	2.87 ± 0.22 (416)	$4.54*10^4 \pm 1.74*10^4$ (387)
Transect 2	598.9 ± 16.2 (660)	6.81 ± 0.02 (574)	22.93 ± 0.07 (667)	13.24 ± 5.82 (425)	3.28 ± 0.18 (407)	$1.39*10^3 \pm 3.73*10^2$ (365)
Transect 3	426.7± 14.5 (577)	6.76 ± 0.03 (487)	23.2 ± 0.05 (584)	3.00 ± 0.10 (459)	2.74 ± 0.96 (429)	$8.45*10^2 \pm 2.97*10^2$ (384)
Napoleon Gulf	100.19 ± 0.6 (160)	7.84 ± 0.07 (120)	27.16 ± 0.1 (160)	4.47 ±3.95 (163)	0.23 ± 0.03 (152)	$5.60*10^2 \pm 1.06*10^2$ (160)

The variation of conductivity and pH of the influent into and effluent out of the stabilisation ponds is depicted in Fig. 2. Electrical conductivity was reduced by 42%; (Fig. 2a) and average pH slightly increased from 7.9 at the influent to 8.3 at the final effluent (Fig. 2b). The increase in pH may be attributed to the photosynthetic activity (which takes up CO_2 from the water leaving the OH^- from the dissociating bicarbonate ion) of the algae. Temperature was more or less the same at the influent and effluent with average values of 26.9 and 26.2 °C respectively over the study period.

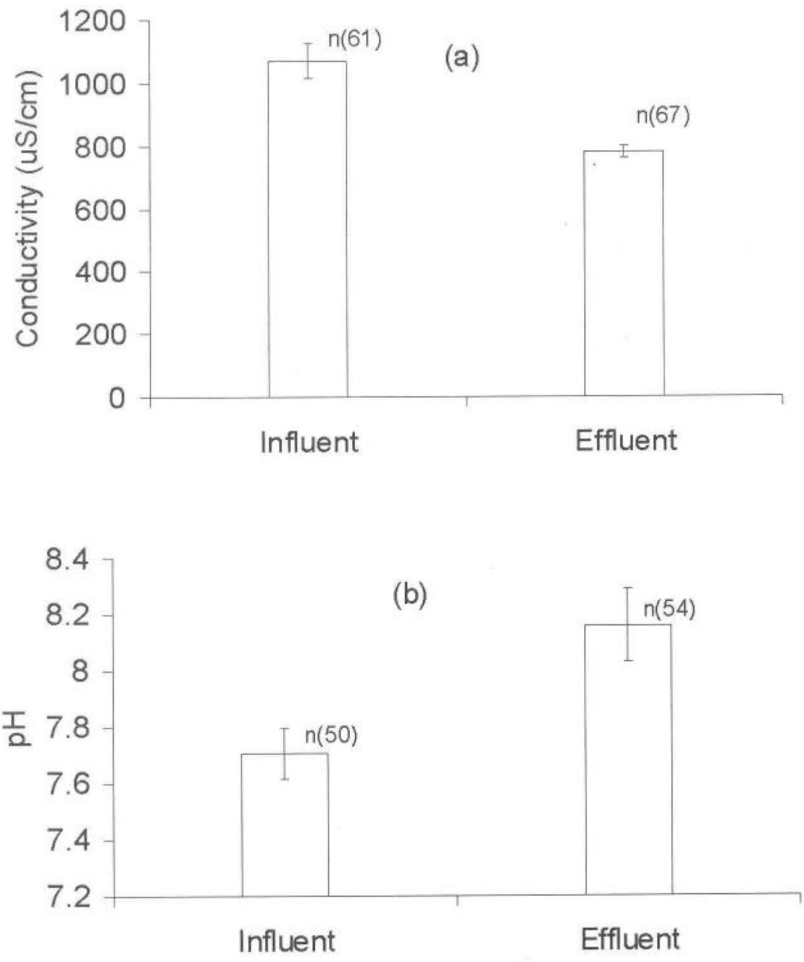

Figure 2. Variation of conductivity (a) and pH (b) in the influent into the ponds and the effluent from the last maturation pond. Bars indicate standard error of the mean

There was a significant reduction (61%) of ammonium-nitrogen from the influent into the ponds to the final effluent (Fig. 3a). There was a 27% increase in nitrate-nitrogen and 46.9% decrease in orthophosphate (Fig. 3a). Increase in NO_3-N could have resulted from the nitrification process of NH_4-N, of which the end product is nitrate. Faecal coliforms were also reduced by 97.5% as the wastewater passed through the ponds (Fig. 3b).

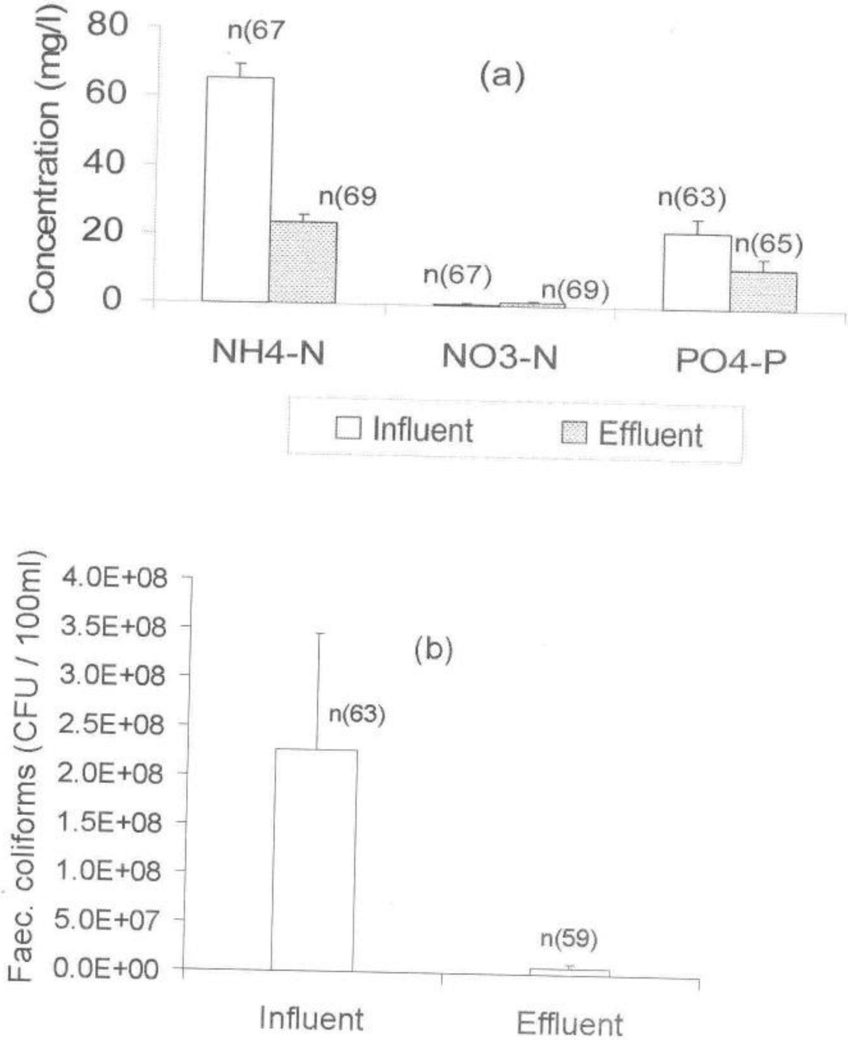

Figure 3. Variation of nutrients (a) and faecal coliforms (b) in the influent into the ponds and the final effluent from the last maturation pond. (Note: The values of nitrate and orthophosphate on the graph scale are ten times more than the actual values)

Measurements were also made (only 3 times) on Cr, Pb, Zn and Cd at the beginning of this study. No heavy metals were detected in the influent except chromium whose concentration was 0.01 g/l.

Overall, high values of conductivity were recorded at the western edges of the wetland (between 25-175 m of the 3 transects) and lowest in the middle (Fig. 4). The values of conductivity rose again towards the eastern end of the wetland (between 500 – 600 m along the transects).

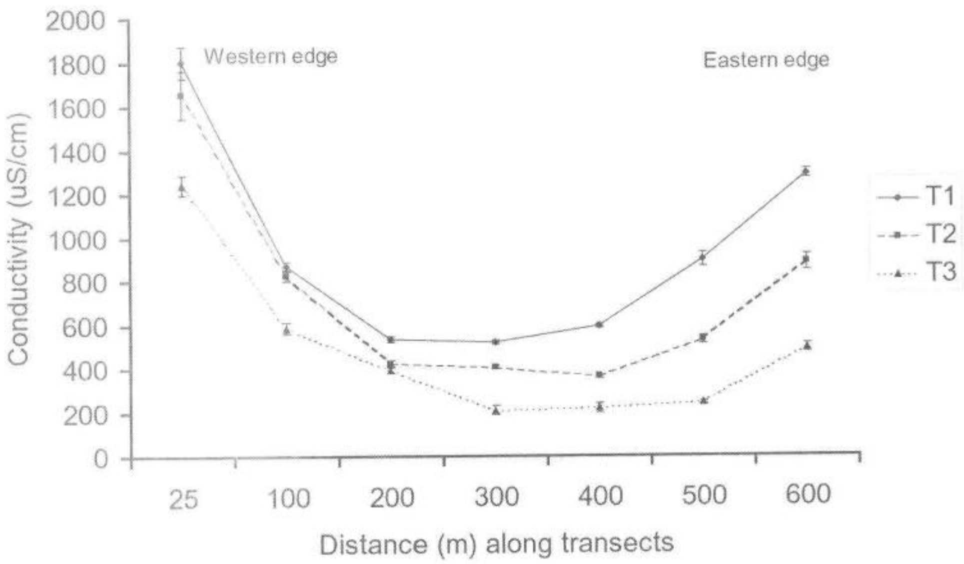

Figure 4. Variation of conductivity in the Kirinya West wetland

The high values of conductivity at the western end of the transects were attributed to the wastewater effluent from the last maturation pond which discharges at the north-western end of wetland (Fig. 1). This indicates that the wastewater from the ponds is not evenly distributed in the wetland but flows as a stream through the wetland en route to Napoleon Gulf in Lake Victoria.

The high values at the eastern end are attributed to the leakage of wastewater from the facultative pond into the storm water drainage channel, which is located between the two anaerobic ponds and the facultative pond. Sewage frequently flows into the wetland during both dry and wet seasons.

Since most of the flow (400 – 1500 m^3/d of effluent) is discharged from the last maturation pond (MP_2 – Fig. 1). It is logical to state that most of the wastewater flows on the western end of the wetland on its way to Napoleon Gulf in Lake Victoria. For the three transects, the values of conductivity had the following trend: Transect 1 > Transect 2 > Transect 3. The decrease in conductivity from Transect 1 to transect 3 is attributed to the retention of ions (e.g. ammonium ions by the wetland).

The values of pH were more or less the same along the individual transects, though values were slightly higher at the western parts of the transects (between 25-75m) as shown in Fig. 5. pH values were significantly different ($p=0.028$) in the wastewater along the three transects and Dunnet's multiple comparison revealed the following trend: Transect 1> Transect 2> Transect 3. Values of pH along transects two and three were within the range reported for natural wetlands (Howard-Williams and Gaudet, 1976; Kansiime *et al.*, 1994; Muthuri and Jones, 1997; Kipkemboi, 1999). Temperature exhibited the same trend.

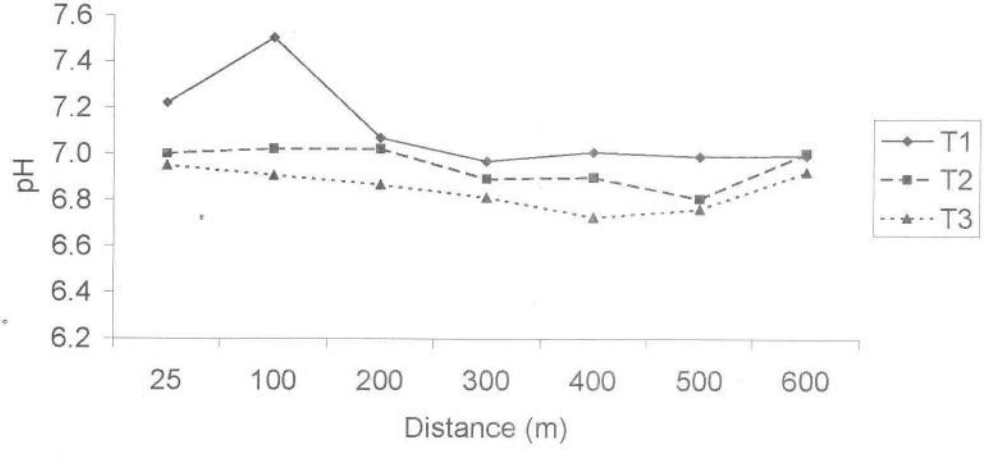

Figure 5. Variation of pH in the Kirinya West wetland

The variation of faecal coliforms along the three transects is shown in Fig. 6. The highest numbers of coliforms were measured along transect one. The highest values were recorded at the western end of the wetland, the lowest in the middle and concentrations rose again towards the eastern end of the transects. The concentration of coliforms was significantly different (ANOVA, $p=0.04$) along the three transects. Following analysis of varience , multiple comparisons revealed that faecal coliform numbers along T1>T2=T3. The high values of faecal coliforms recorded between 300 and 400 m along transects was due to the leakage of wastewater from the facultative pond.

Along transect 2 the variation on the concentration of faecal coliforms showed a similar pattern as that of conductivity (Fig. 7). Since high concentrations of coliforms may be attributed to the effluent and leakage from the stabilisation ponds, the high values in the wetland may be traced back to the same source.

The positive correlation ($r = 0.77$), though not significant ($p = 0.51$ $n = 242$) between conductivity and faecal coliforms indicates that the ions contributing to conductivity and faecal coliforms most likely come from the same source, the effluent from the stabilisation ponds.

The concentration of ammonium-nitrogen was highest at the western and eastern edges of the wetland and lowest in the middle (Fig. 8). The average concentration of ammonia was lowest along transect 3. The concentration of ammonia depicted a similar pattern to conductivity (Fig. 9). The source of high concentrations is likely a result of effluents from the stabilisation ponds into the wetland.

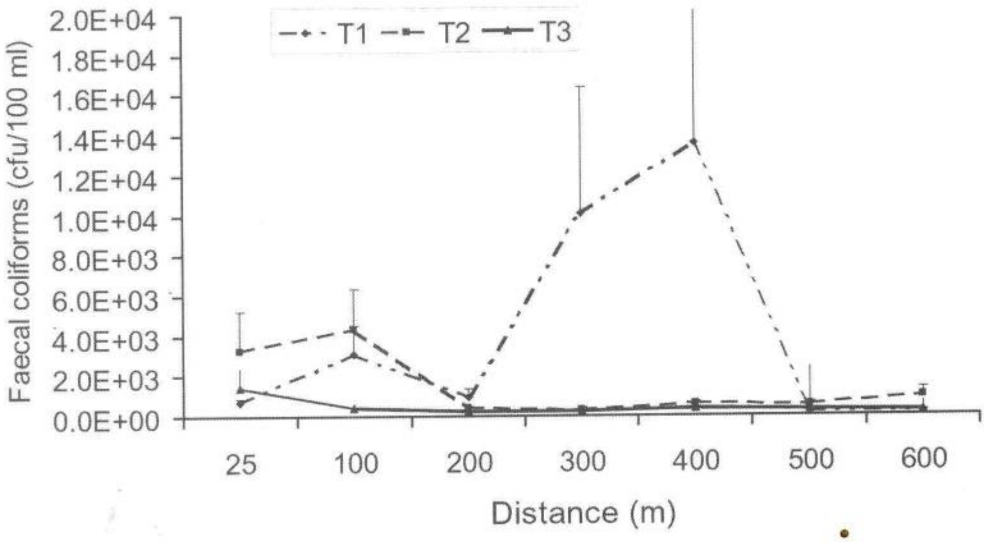

Figure 6. Variation of faecal coliforms in the Kirinya West wetland. Note: Values for transect one are ten times higher than indicated on the scale

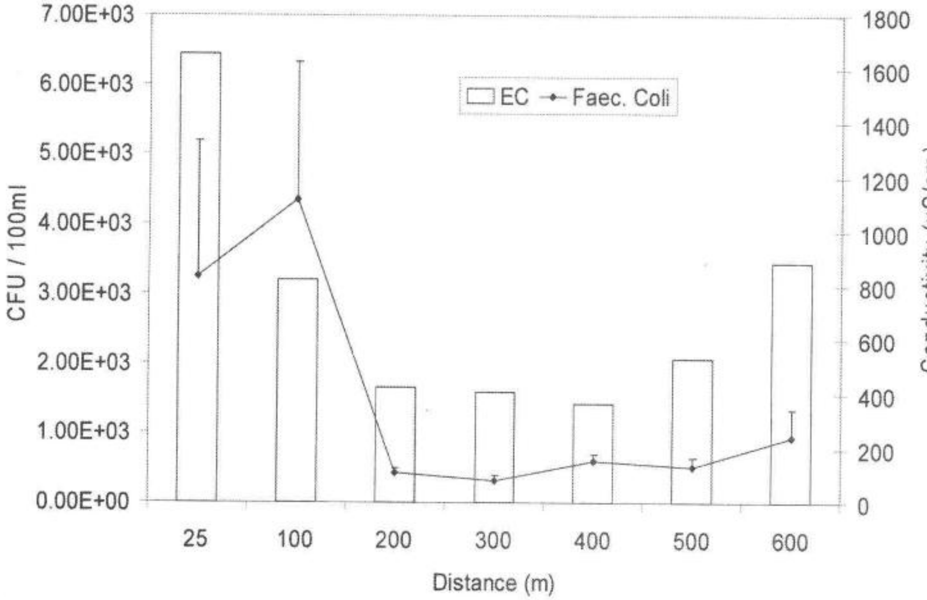

Figure 7. Variation of conductivity and faecal coliforms (no/ 100 ml) along transect 2

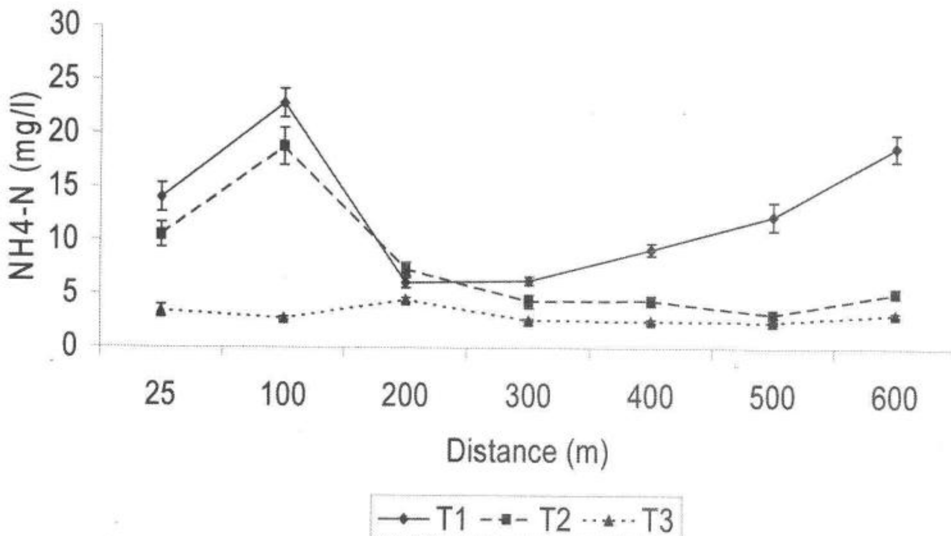

Figure 8. Variation of ammonium-nitrogen in the Kirinya West wetland

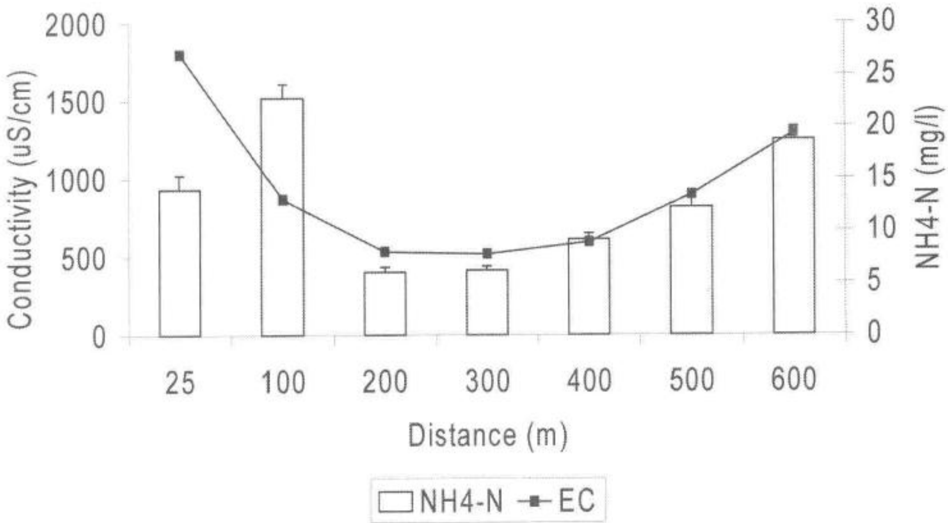

Figure 9. Variation of conductivity and ammonium-nitrogen in the Kirinya West wetland

Water quality was also assessed in the Napoleon Gulf-Lake Victoria at sites LK1, LK2 and LK3 as indicated in Fig. 1. Conductivity in the lake varied between 84 to 110 μScm^{-1} (Fig. 10). The concentration of faecal coliforms was generally low compared to the inflow into the wetland and that within the wetland (Fig. 11), though their occurrence in Napoleon Gulf, suggests that wastewater reaches the lake. The concentrations were much lower (4 log units lower) in the lake than those recorded at the inflow into the wetland. The concentration of ammonia and orthophosphates in the lake were low with average values of 0.3 and 0.06 mg/l respectively.

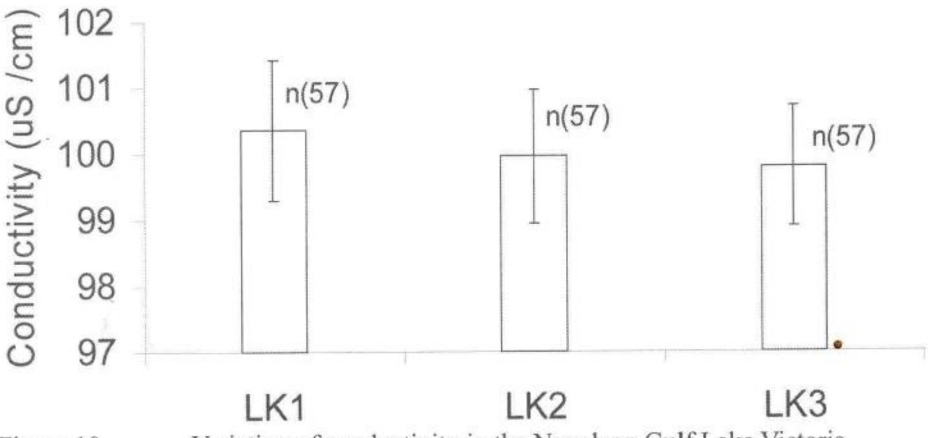

Figure 10. Variation of conductivity in the Napoleon Gulf Lake Victoria

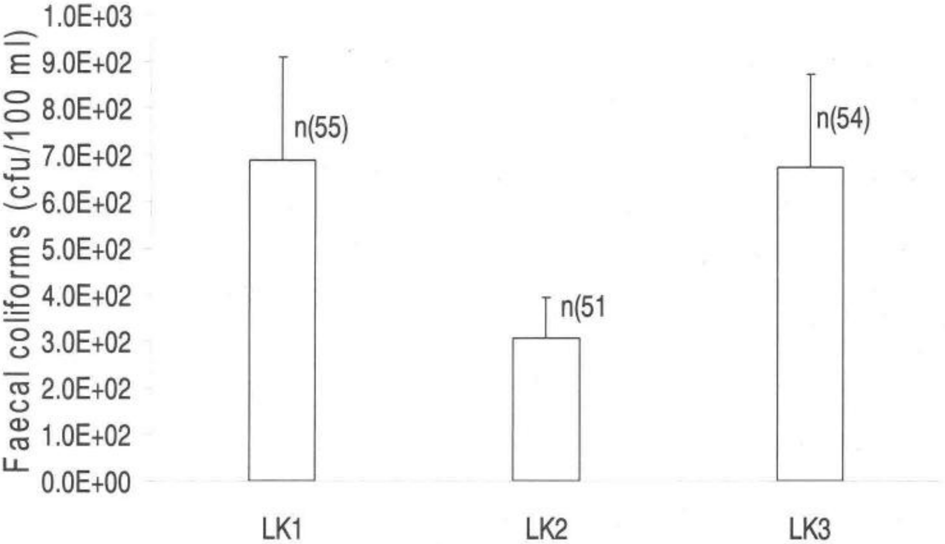

Figure 11. Variation of faecal coliforms (CFU/100ml) in the Napoleon Gulf Lake Victoria

CONCLUSIONS

The values of conductivity and concentrations of nutrients and faecal coliforms measured in this study, clearly demonstrate that the wastewater from the stabilisation ponds is channelled in Kirinya West wetland. Most of it flows on the western edge of the wetland in the same location where the effluent from the ponds is discharged. Low values of most variables at the swamp-lake interface of Napoleon Gulf, Lake Victoria, provide evidence that the Kirinya wetland, still provides some tertiary treatment, as the concentration and values of most variables decrease through the swamp towards the lake. Ammonium nitrogen from the last maturation pond further decreased by 80% and faecal coliforms by 98%. Overall the values in the effluent (nutrients and faecal coliforms) from the ponds were still higher than those recommended by NEMA for effluent discharge into water or on land (NEMA, 1999) Hopefully, the wetland will provide more effluent treatment (up to tertiary level) after it has been bio-manipulated and the wastewater distributed over a large expanse of the wetland.

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