Potential impacts of Kirinya wetland in treating secondary municipal effluent from Jinja stabilisation ponds

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Abstract

Kirinya West wetland is located on northern shores of Lake Victoria in Jinja- Uganda. The wetland receives secondary treated effluent from the stabilisation ponds owned and operated by National Water and Sewerage Corporation. The effluent finally enters Lake Victoria at the Napoleon Gulf. The findings reported in this paper were aimed at establishing the baseline water quality before the bio-manipulation of the wetland to 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 hence its treatment efficiency. The baseline data indicate that there is significant improvement of water quality as the wastewater flowed through the ponds (61% decrease in NH_4-N, 46.9% for o-PO_4 and 98% for faecal coliforms). There was 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, there is channelised flow and most of the wastewater flows at the western edge of the wetland. The effluent from the stabilisation ponds is discharged at the north–western edge of the wetland. Bio-manipulation increases the current treatment efficiency of the wetland, as the contact between plants and the wastewater increases. The construction of the wastewater distribution system is underway.

Keywords: Wetlands, wastewater treatment, Kirinya West wetland, Lake Victoria

Introduction

Lake Victoria, shared by Uganda, Kenya and Tanzania, is important because of its economic, social and aesthetic values to the people of these and other neighbouring countries, who depend on it, especially for fish and drinking water. Unfortunately, the lake has undergone several ecological changes, which are manifested in the occurrence of algal blooms, low levels of oxygen in the water, frequent fish- kills and the spreading of the water hyacinth (Hecky, 1993). One of the contributors to the deterioration of the lake water quality is the input of nutrients (especially N&P) from the catchment.

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 need for cheap and appropriate technology, which can exploit the local conditions such as 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 East Africa in particular (Denny, 1997; Kansiime and Nalubega, 1999; Okurut, 2000). Hence, there is need to understand the processes and conditions necessary for effective wastewater treatment using natural wetlands and its subsequent application in the tropics. The Lake Victoria Environmental Management project (LVEMP), which was formed by the three East African countries, in its efforts to address the adverse ecological changes in the lake, is looking at the use of natural and constructed wetlands (through some of the project sub-components) to treat wastewater from municipalities located in the Lake Victoria catchment. Most of these treatment facilities of the municipalities are malfunctioning and, as a result, discharge partially treated or untreated wastewater into Lake Victoria.

The Integrated Tertiary Municipal Effluent Treatment Pilot Project of the LVEMP is addressing the overall impact of municipal effluents on Lake Victoria. The pilot project in Uganda will bio-manipulate the Kirinya West wetland to optimise its capacity to provide tertiary treatment of municipal wastewater from Jinja town in Uganda. The bio-manipulation will involve 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 plants and associated microbial communities, which will further enhance the removal of nutrients and bacteriological pollutants. Currently, the effluent flows into the wetland as a stream and is chanelised. The effluent from the stabilisation ponds eventually flows into Lake Victoria at the Napoleon Gulf. The objective of this research was to assess the current performance of Kirinya waste stabilisation ponds and the water quality in Kirinya West wetland before 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). 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 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. This 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.

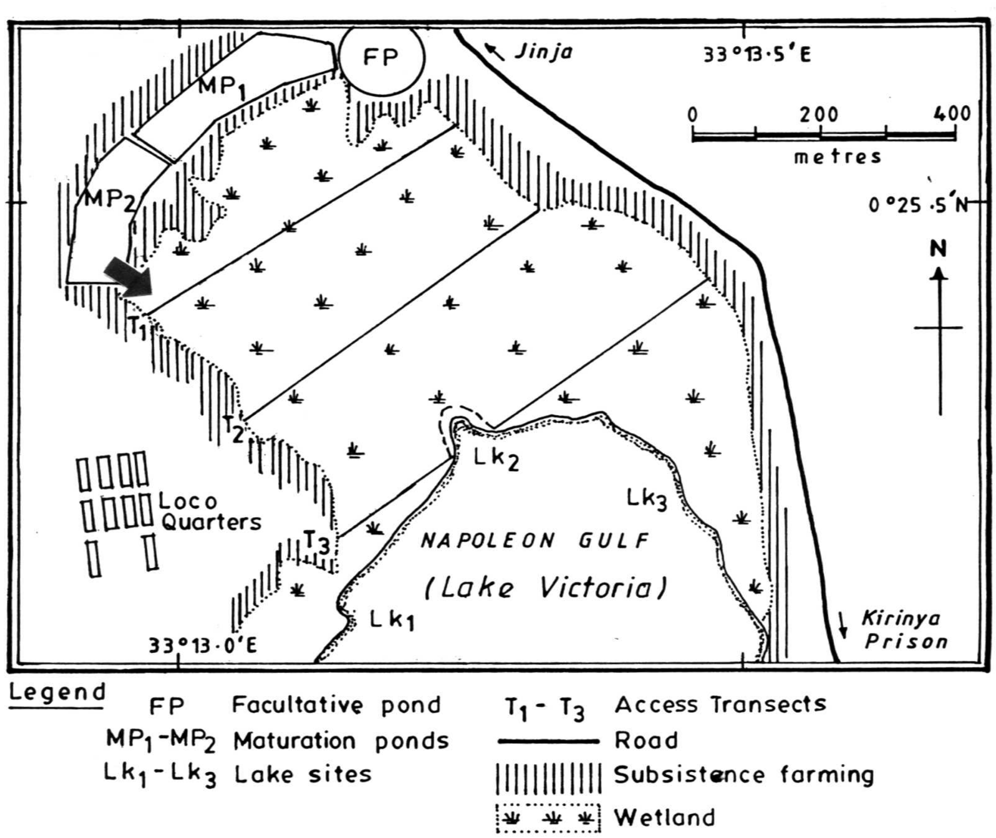

Figure 1. Map showing the location of Kirinya stabilisation ponds, the wetland and access roads

The initial phase of this project 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 far higher than that of the water of Lake Victoria, where the wastewater from the stabilisation ponds is finally discharged. The lake water has a background conductivity of about 90 μS/cm whereas the wastewater from the ponds exhibits variable values ranging from 700 – 1500 μS/cm. This condition makes it possible to identify, at least to a certain extent, the flow of the wastewater in the wetland. Areas of high conductivity were associated with the flow of wastewater from the ponds. Conductivity in the wetland was measured in the water column and along three access transects (T1–T3) cutting through the wetland (Figure 1) and placed at intervals of 25m. During the initial preparation of the access transects, papyrus culm bundles were laid on the path to ease movement along transects. However, the papyrus bundles were not long lasting, as they would weaken within a short time. This made maintaining the access transects quite expensive. As a result, the project team, later decided to use eucalyptus poles to make ladders that were laid on the transects. Though a bit expensive, they lasted longer and team members and visitors could easily and confidently enter the wetland.

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 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. Calibration of portable 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 25m, 100m and thereafter after every 100m along each transect. In addition, conductivity, temperature and pH of the samples were also measured in the field. 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. For physico-chemical analyses, 500 - 1000 ml bottles were used. 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. Sample bottles were also rinsed several times with the sample to be collected. 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 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). Colorimetric determinations were carried out 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. Correlation was used to establish relationships between given variables.

Results and discussion

Electrical conductivity was reduced by 42%; (Figure 2a) and average pH slightly increased from 7.9 at the influent to 8.3 at the final effluent (Figure 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, the respective mean values being 26.9 and 26.2 ^{o}C over the entire period.

a) b)

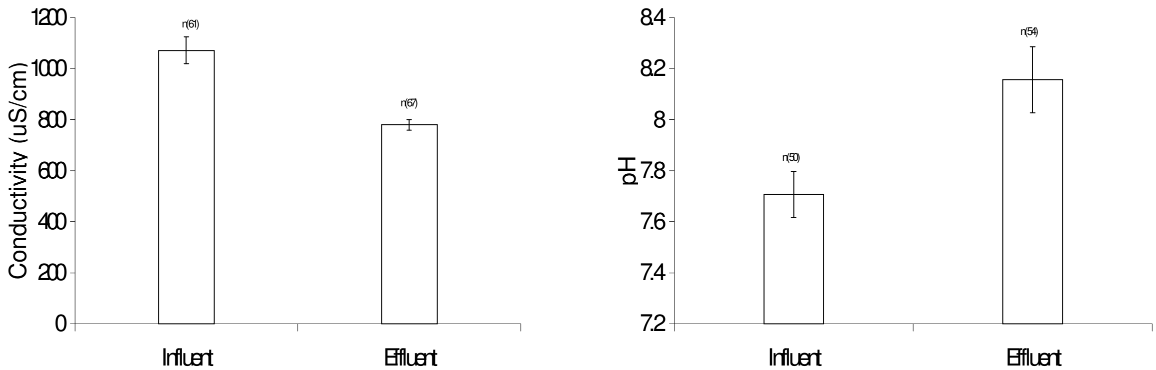

Figure 2. Variation of conductivity (a) and pH (b) in the influent into the ponds and the effluent from the last maturation pond. Bars indicate standard error of the mean.

There was a significant reduction (61%) of ammonium-nitrogen from the influent into the ponds to the final effluent (Figure 3a). There was a 27% increase in nitrate-nitrogen and 46.9% decrease in orthophosphate (Figure 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 (Figure 3b).

a) b)

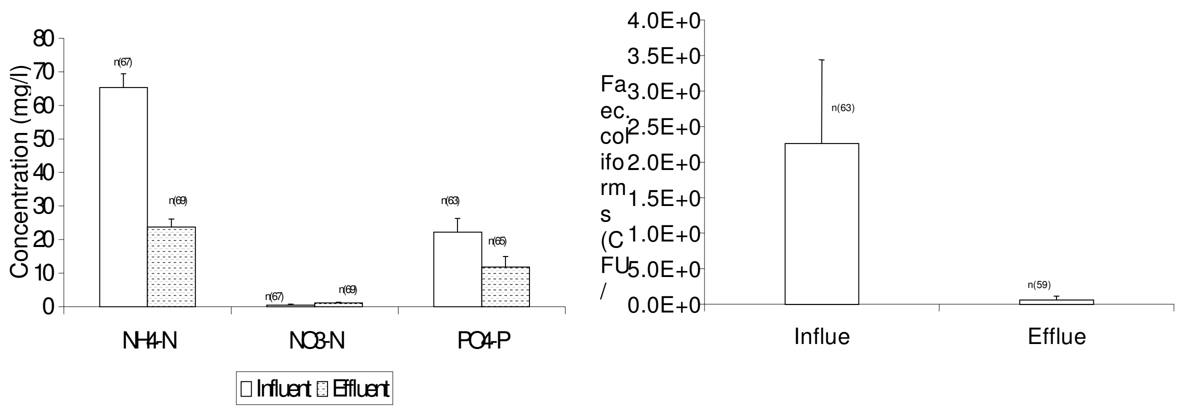

Figure 3. Variation of nutrients (a) and faecal coliform (b) in the influent into the ponds and the final effluent from the last maturation pond. (Note: The values of nitrate and orthophosphate on the graph scale are ten times more than the actual values).

Measurements were also made (only 3 times) on Cr, Pb, Zn and Cd at the beginning of this project. No metals were detected in the influent except chromium whose concentration was 0.01 g/l. None was detected in the effluent from the last maturation pond.

To assess the water quality in the Kirinya West wetland, intensive measurements of conductivity were made along the three transects during 1999. Measurements of conductivity were made *in situ* in the water column below the mat. Sampling points were located at an interval of 25m. The direction of measurements were from the west

(LOCO Quarters) to east (Kirinya prison) along each transect. Because of many sampling points, it was not possible to make measurements at all the three transects in a single day. However, measurements along the three transects were carried out within 2-3 days of a given sampling week or event.

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 (Figure 4). The values of conductivity rose again towards the eastern end of the wetland (between 500 – 600 m along the transects).

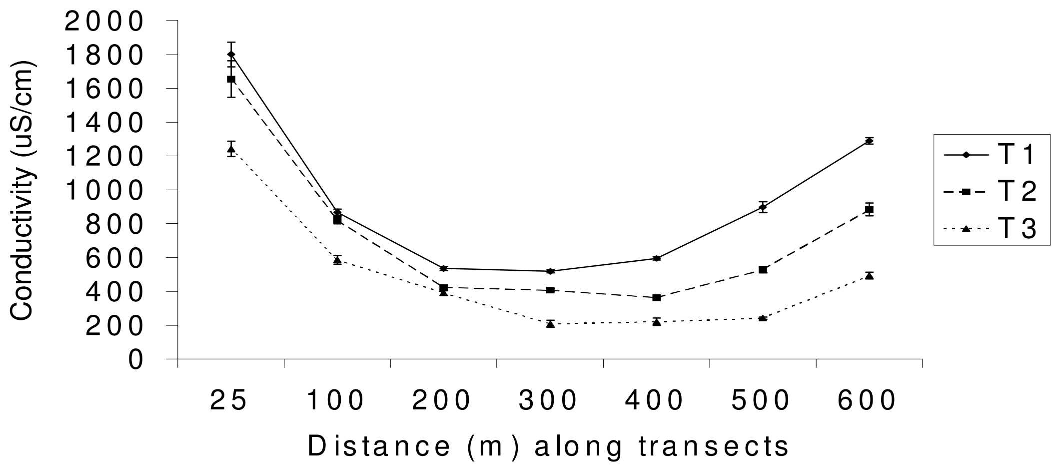

Figure 4. Variation of conductivity in the Kirinya West wetland

The high values of conductivity at the western end of the transects are attributed to the wastewater effluent from the last maturation pond which discharges at the north-western end of wetland (Figure 1). This implies 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 – 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 is commonly seen flowing into the wetland even during the dry season. Since most of the flow (400 – 1500 m^3/d of effluent) is discharged from the last maturation pond (MP_2 – Figure 1), one can argue that most of the wastewater flows on the western end of the wetland on its way to Napoleon Gulf-Lake Victoria. For the three transects, the values of conductivity had the following trend: Transect 1 > Transect 2 > Transect 3.

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 Figure 5. Overall, the average pH value along the individual transects were 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.

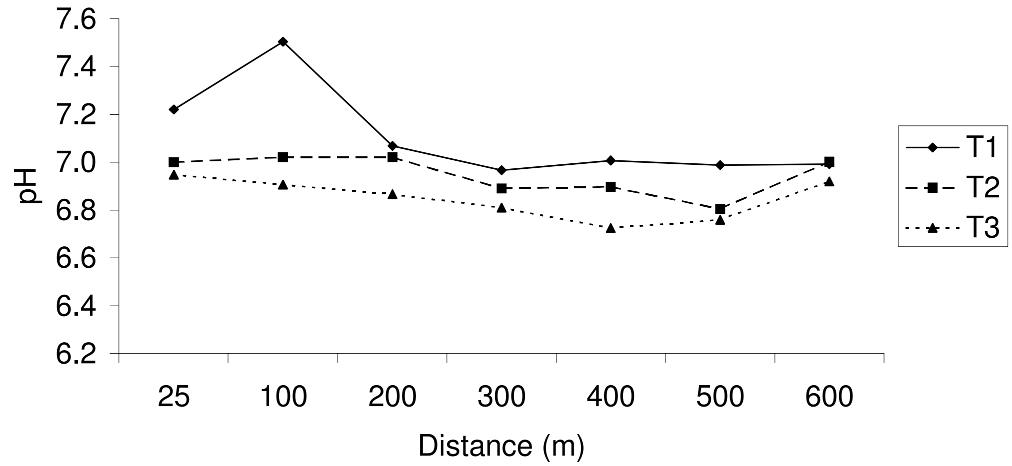

Figure 5. Variation of pH in the Kirinya West wetland.

After establishing the possible wastewater flow patterns in the wetland, nutrients (nitrogen and phosphorus) and faecal coliforms were measured at selected locations along the transects. Measurements were taken at 25, 100 m and thereafter at a distance of 100 m along each transect. Measurements along the three transects were taken on the same day of sampling with an hour interval between transects.

The variation of faecal coliforms along the three transects is depicted in Figure 6. The highest numbers of coliforms were observed along transect one. The highest values were recorded at the western end of the wetland, the lowest in the middle though the concentrations rose again towards the eastern end of the transects. Overall, the concentration of coliforms were significantly higher along transect one compared to transects two and three. The levels of faecal coliforms along the latter transects were not significantly different though the numbers were lower along transect three. The high values of faecal coliforms recorded between 300 and 400 m along transects is attributed to the leakage of wastewater from the facultative pond.

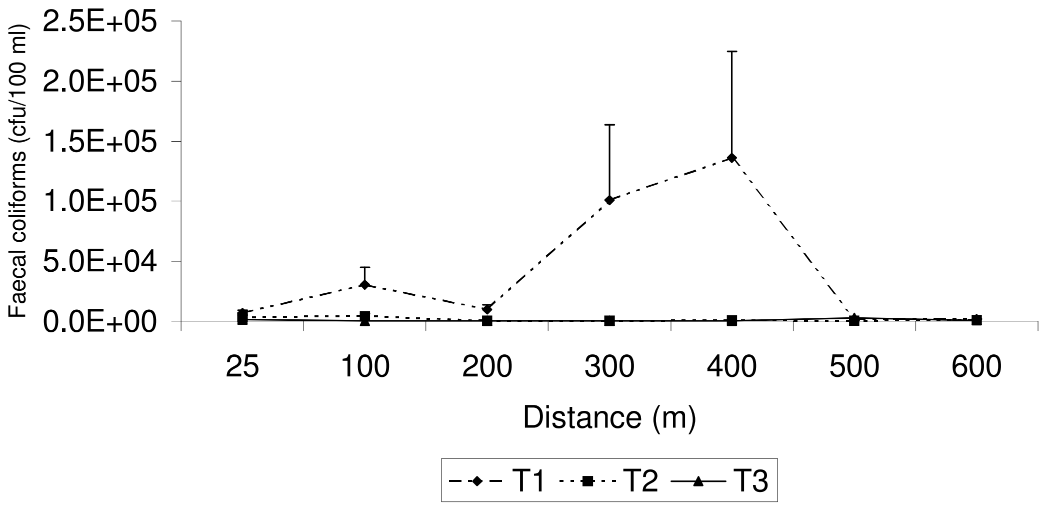

Figure 6. Variation of faecal coliforms in the Kirinya West wetland

The concentration of faecal coliforms depicted a similar trend to conductivity and the values of transect 2 are shown in Figure 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 high correlation (r = 0.77) between conductivity and faecal coliforms indicates that the ions contributing to conductivity and faecal coliforms originate from the same source, in this case, the effluent from the stabilisation ponds.

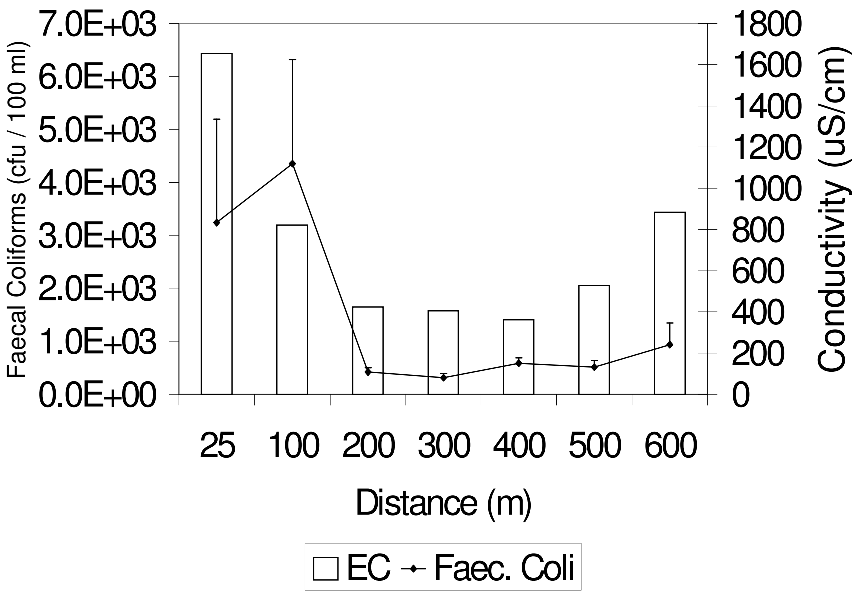

Figure 7. Variation of conductivity and faecal coliforms (no/ 100 ml) along transect 2.

The concentration of ammonium-nitrogen was also highest at the western and eastern edges of the wetland and lowest in the middle (Figure 8). The average concentration of ammonia was lowest along transect 3. The concentration of ammonia also depicted a similar trend to conductivity (Figure 9). The source of high concentrations is most likely to be, as has been stipulated for other variables, effluent from the stabilisation ponds.

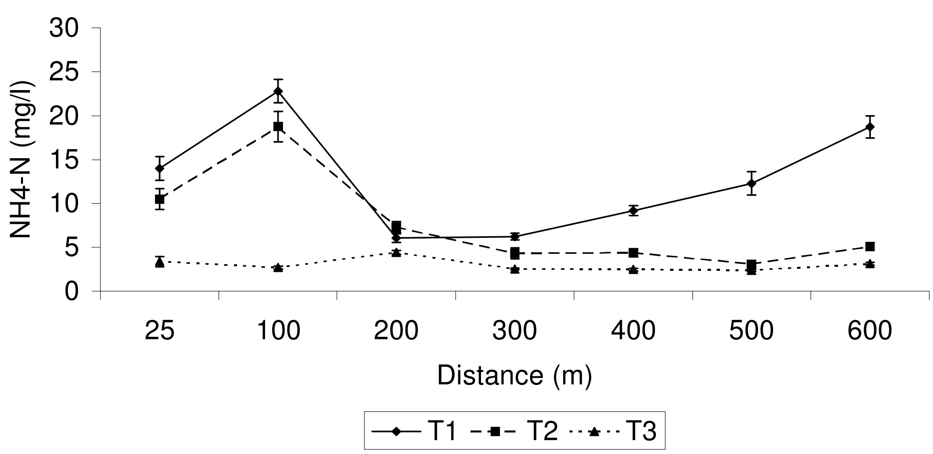

Figure 8. Variation of ammonium-nitrogen in the Kirinya West wetland.

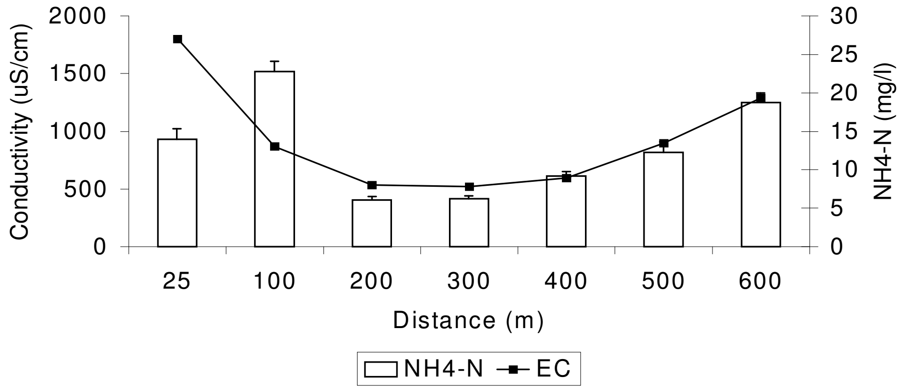

Figure 9. Variation of conductivity and ammonium-nitrogen in the Kirinya West wetland.

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

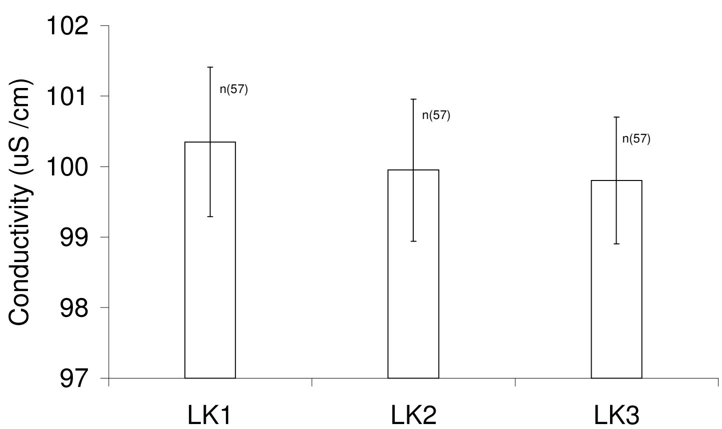

Figure 10. Variation of conductivity in the Napoleon Gulf Lake Victoria.

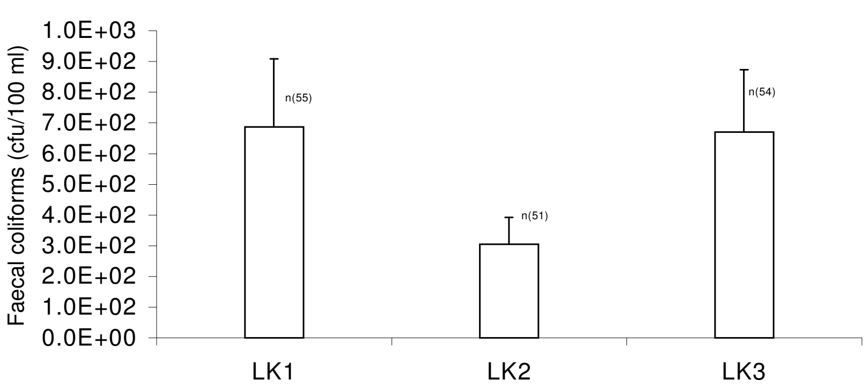

Figure 11. Variation of faecal coliforms (CFU/100ml) in the Napoleon Gulf Lake Victoria.

Conclusion

The data collected so far 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. However, the wetland provides tertiary treatment, as the concentration and values of most variables decrease through the swamp towards the lake. For example, ammonium nitrogen from the last maturation pond further decreased by 80% and faecal coliforms by 98%. However, the values in the effluent from the ponds were still higher than those recommended by NEMA for effluent discharge into water or on land (NEMA, 1999). It is hoped that the wetland would provide more treatment (up to tertiary level) after it has been fully bio-manipulated and the wastewater distributed over a large expanse of the wetland as shown in Figure 12. The construction of the wastewater distribution system is currently being carried out.

The data that will be collected after the bio-manipulation of the wetland will be compared to the baseline data (reported in this paper) in order to demonstrate the potential of natural wetlands in treating wastewater. It is hypothesised that in addition to the expected further improvement in water quality as the wastewater flows through the wetland, the variation of water quality along the longitudinal axis of given transects will be more or less the same.

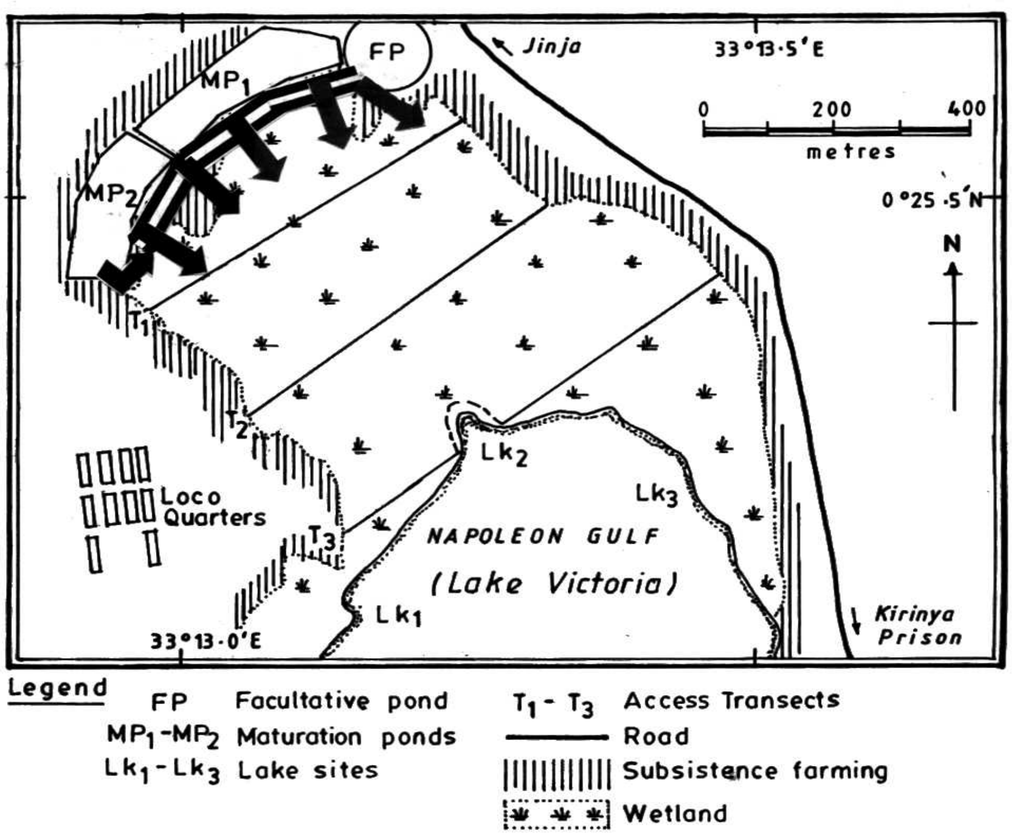

Figure 12. Schematic representation of the proposed water distribution system (represented by big arrows) over Kirinya West Wetland

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