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REMOVAL OF COLIFORM AND SOLIDS IN A TROPICAL CONSTRUCTED WETLAND

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ABSTRACT

Pilot scale studies were conducted to determine the performance of a subsurface horizontal flow constructed wetland in the tropics in the period April to July 2003. The wetland located at Jomo-Kenyatta University of Agriculture and Technology (JKUAT), Kenya, had sewage treatment works consisting of four cells set in parallel each 22.5m^2. Three of the cell had gravel and in two of the cells with gravel the tropical macrophyte *Cyperus Papyrus* was introduced. The wetland received a continuous feed of settled sewage from a primary facultative pond. Performance of the wetland was evaluated in terms of removal of bacterial pathogens and suspended solids. This was done under different hydraulic loading rates. Fecal coliform removal in the wetland of up to three log units was realized. The removal was found to be influenced by the influent coliform count and not the hydraulic retention time. When fecal count in the influent was less than or equal to 2 log units 99.9 % removal was realized. A moderate removal rate of up to 50 % for Total Suspended Solids (TSS) was obtained. The loading rates deduced from the study for TSS was 122 Kg/Ha.d.

Key Words: *Alternative wastewater treatment, Subsurface horizontal flow (SSF), Macrophyte*

Introduction

In the field of wastewater treatment, the three categories of human enteric organisms of greatest consequence in producing disease are bacteria, viruses and amoebic cysts (Tchonabouglas, 1990). One objective of wastewater treatment is to eliminate these pathogenic organisms, from the wastewater. Unfortunately, these organisms, which are highly infectious, are responsible for many thousands of deaths each year in areas with poor sanitation, especially in the tropics. The need for utilizing cheap, effective, alternative technologies such as constructed wetlands in wastewater management is essential in such circumstances (Okia, 2000). Several study reports have demonstrated the potential of natural and constructed wetlands in reducing the population of various types of pathogens to very low concentrations and with reduced public health risk. Based on reduction in indicator species, pathogens are thought to be removed in both surface flow (SF) and subsurface flow (SSF) wetlands (Watson et al, 1989; Gersberg et al, 1989). Performance data for small municipal constructed wetland systems in North America and Europe showed reduction in coliform ranges from 82 % to nearly 100 % (Watson et al, 1989).

The processes responsible for the reduction of pathogen population in wetland treatment systems are known to be controlled by a combination of physical, biological and chemical factors (Gersberg et al, 1989). Viruses may be adsorbed by soil, the treatment media and organic litter, or deactivated because in time they die when outside the host. Bacteria are removed by sedimentation, ultraviolet radiation, chemical reactions, natural die-off, exposure to biocides released by the plant roots, and predation by zooplanktons. The contribution of each of the above routes is suggested to be a function of wastewater flow rates, nature of the macrophytes and type of the wetland.

A potential problem of suspended solids is that they can lead to the development of sludge deposits when untreated wastewater is discharged in the aquatic environment. In the Subsurface flow (SSF) wetlands, wastewater suspended solids are removed primarily by filtration through the substrate media.

Objectives of study

The specific objectives of this study were;

(i) Determination of fecal bacteria and Total suspended solids removal efficiency, in a subsurface horizontal flow constructed wetland under tropical conditions.

(ii) Determination of the effect of hydraulic loading/ hydraulic retention time and the fecal coliform decay rates, in a single cell subsurface flow constructed wetland.

Materials and method

The pilot wetland was built in such a way that only controlled and measurable quantities of wastewater and rain were the inputs into the system. The wetland consisted of four cells set in parallel, each with an area of 22.5m^2. The macrophyte *Cyperus papyrus* was introduced into two of these cells in the month of October, in 2002, using clumps at a spacing of 0.75m by 0.75m. Prior to the planting of the macrophyte, wastewater had been introduced in the wetland in the month of September.

The wetland cells were 7.5m long and 3m wide (Fig 1). They had vertical sides and a bottom horizontal slope of one percent. Cells a, b, and d were filled with gravel to a depth of 0.6m. The gravel ranged in size from 9-37mm, with a porosity of 45 % and a hydraulic conductivity Ks = 4050 m^3/m^2.d. Cells a and d were vegetated while cell b was unvegetated and cell c was a pond. Cells b and c acted as the control.

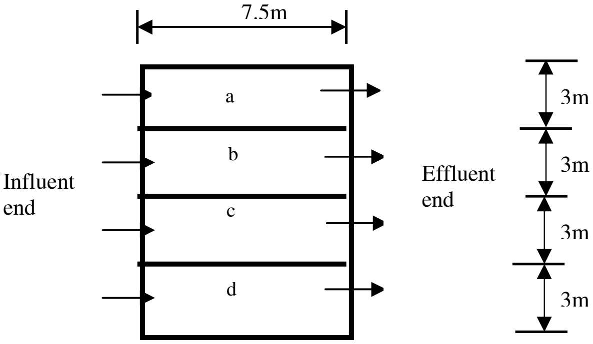

Figure: 1 Plan layout of the pilot scale constructed wetland.

The experimental work on performance evaluation of the wetland for pathogen removal was based on the use of indicator organisms, specifically fecal coliforms as described in standard methods (APHA, 1995). Influent and effluent samples used in the investigation were grab samples taken weekly at between 0700hrs-0900hrs, as wastewater was continuously loaded into the wetland cells. Sampling involved:

(a) Determining the flow rate at the inlet and outlet of the cells: Volumetric method- using a beaker and stopwatch.

(b) Sampling at the influent point of the cells using cleaned/ sterilized glass containers.

(c)Taking effluent samples from each of the 4 cells using cleaned/ sterilized glass containers

Sterilized glass bottles were used for sample collection throughout the study period. The membrane filtration technique was used. In the laboratory, sample sizes were determined according to standard method recommendation for secondary effluent. The samples were filtered through a cellulose nitrate membrane filter of a pore size of 0.45µm after which the membrane was placed on an absorption pad soaked in lauryl sulphate tryptose broth solution. Samples were incubated at 44±0.2^{o}C hrs for 24 hrs and thereafter, all characteristically yellow colonies were counted as fecal coliforms. The results were expressed as number of organisms in 100 ml of the sample. Determination of the total suspended solids was through gravimetric method- filtering with GF/A filter paper and residue dried at 103-105°c.

Experimental results

The pollutant concentration ranges in the wastewater fed into the pilot scale constructed wetland are given in Table 1.

Table 1: Pollutant concentration range in the primary facultative pond effluent at JKUAT treatment works (April-July 2003)

Parameter	Mean*	Standard Error	Range
TSS (mg/l)	57.6	5.7	26.5-96.8
FC (Count /100ml)	1415	799	150-8250

*(Mean based on 15 sampling occasions)

Fecal coliform removal

High influent and effluent fecal coliform counts were observed after rainfall events. Effluent fecal coliform concentrations from the pilot scale constructed wetland are given in Table 2.

Table 2: Fecal coliform effluent concentration range from the wetland cells

Cell	A	B	C	D
FC (Count/100ml)	0-1250	0-550	100-2750	0-900
Mean*	125	65	640	135
Standard error	156	54	260	96

*(Mean based on 15 sampling occasions)

The average percentage Fecal coliform removal from the pilot scale experiment is given in Fig. 1 The control cell b exhibited higher removal than the rest of the cells.

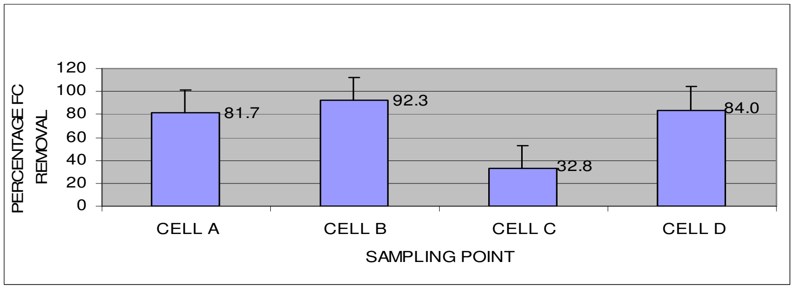

Figure: 1. Average percentage fecal coliform removal

Effect of hydraulic retention time on fecal coliform removal was evaluated using data generated during sampling, at the different hydraulic loading rates applied. The Fecal coliform count in the effluent from the pilot scale experiment did not appear to depend on the retention time as depicted in Fig 2 a-c below. Equally, it was not analytically possible to determine the coliform decay rates using the experimental data.

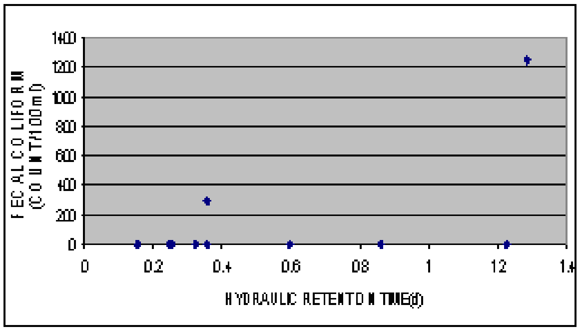

Figure: 2 a Fecal coliform count in the effluent of cell a Vs hydraulic retention time

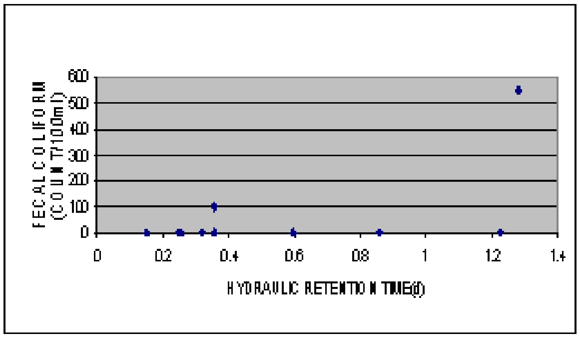

Figure: 2 b Fecal coliform count in the effluent of cell b Vs hydraulic retention time

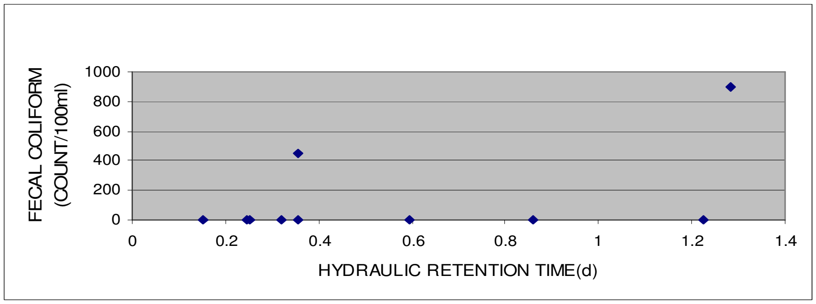

Figure: 2 c Fecal coliform count in the effluent of cell d Vs hydraulic retention time

Total suspended solids (TSS) removal

Table 3 shows the TSS effluent quality ranges from the pilot scale cells.

Table 3 TSS effluent quality ranges in the pilot scale experiment

Cell	A	B	C	D
Effluent TSS(mg/L)	1-66.5	1-62	13-80	2-75.5
Mean*(mg/L)	31.3	29.5	47.1	32.5
Standard error of mean	5.4	5.3	5.2	5.6

*(Mean based on 15 sampling occasions)

Moderate removal rates were observed for TSS as depicted in Fig 3. Cells with gravel had better removal than the control c which had a pond format. However the difference in performance among the cells with gravel (a, b and d) was not significant statistically at 5% significant level

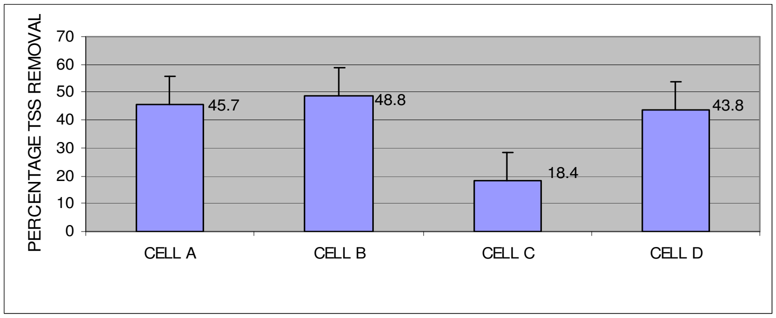

Figure: 3 Average percentage TSS removal in the pilot scale experiment

The influence of the mass loading of TSS on its removal rates in each of the cells was evaluated graphically as shown in Fig 4(i-iv). The mass loading rate was computed as the product of influent pollutant concentration and the hydraulic loading rate. All the cells had a positive correlation between the loading rate and removal rates.

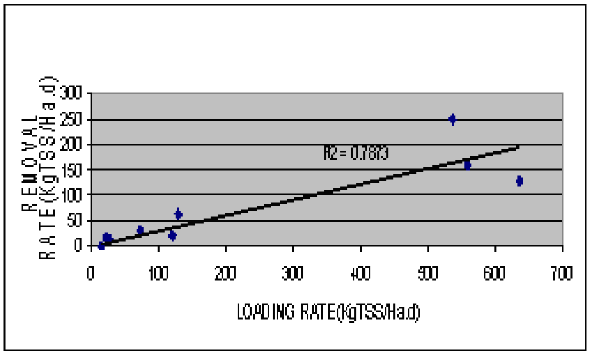

Figure: 4(i) TSS removal rate vs loading rate for cell a

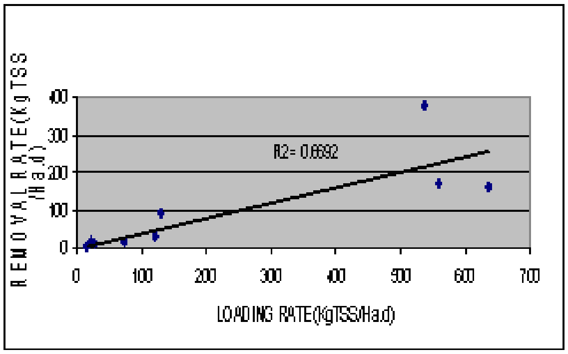

Figure: 4(ii) TSS removal rate vs loading rate for cell b

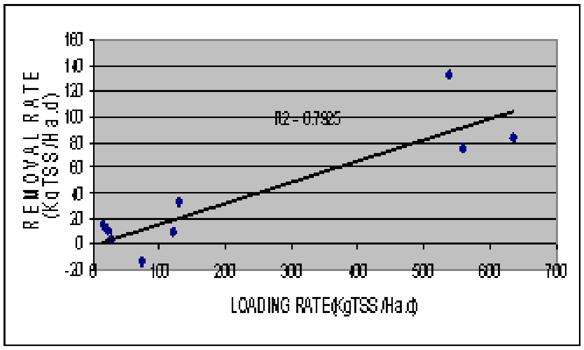

Figure: 4(iii) TSS removal rate vs loading rate for cell c

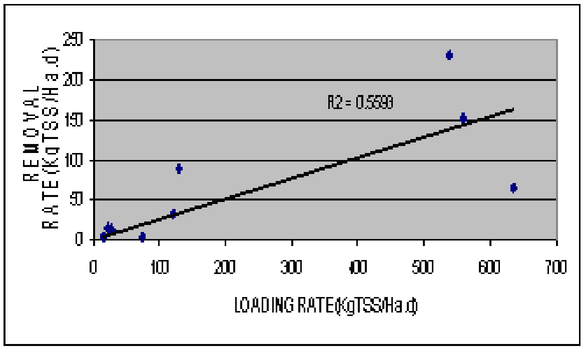

Figure: 4(iv) TSS removal rate vs loading rate for cell d

The maximum applied loading rate at which a linear relationship between loading Vs removal rate was sustained was adopted as the loading rate value for the cell. A TSS loading rate of 122 Kg/Ha.d was determined for all the cells.

The individual retention times for each cell were computed and values plotted against the corresponding percentage TSS removal in each cell as shown in Fig 5.(a-c). No clear pattern was observed in this case, suggesting that filtration, which is the main TSS removal mechanism in constructed wetland

and gravel beds is not entirely time dependent.

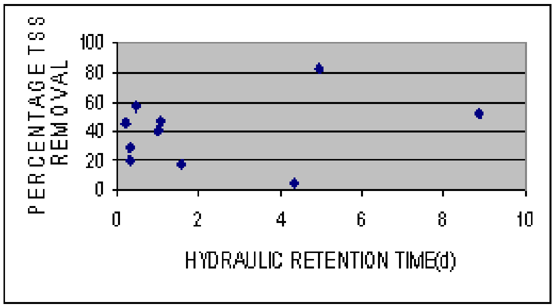

Figure: 5.a Percentage TSS removal Vs hydraulic retention time for cell a

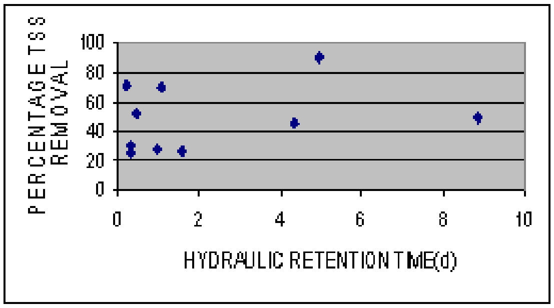

Figure: 5.b Percentage TSS removal Vs hydraulic retention time for cell b

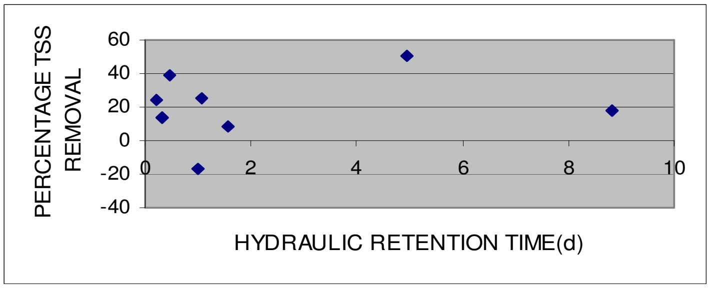

Figure: 5.c Percentage TSS removal Vs hydraulic retention time for cell d

A regression equation was fitted to quantify the removal of TSS in the wetland based on information obtained for the vegetated wetland cells from the pilot experiment: $C_e = 0.10\ C_i^{1.35}$, within the following Limitation; 26.5 mg/L$<C_i<$96.75mg/L, 0.05m/d$<q<$1.18m/d, N=15, $R^2 = 0.3$ Where, C_e = Effluent TSS concentration, C_i = Influent TSS concentration, q = Hydraulic loading rate

Discussion

The variance in fecal coliform removal observed in the effluents of the pilot scale wetland cells, demonstrates the role played by the substratum-root matrix in fecal coliform removal. Higher fecal counts were determined in the effluent of cell c (which had a pond format) compared to the effluent of cells a, b and d. These observation may be explained by the strong interaction that existed between the flowing wastewater and the gravel media in cell b and gravel root-matrix in cells a and d. This promoted the physical processes, namely entrapment and attachment through which the fecal coliform are removed. These processes also identifiable with the removal of suspended solids, together with other subsequent chemical and biological degradation processes are responsible for the reduced fecal coliform numbers in cell a, b and d. These interactions are either non-existent or minimal in the free water column. Consequently the possible pathways were diminished, hence the high fecal populations present in the effluent from cell c. From these observations it can be concluded that maximum interaction between substratum-root matrix and wastewater is necessary for increased reduction in fecal bacteria. Channeling and surface flow would significantly reduce the performance of a subsurface flow wetland system.

The averaged percentage coliform removal in the unvegetated bed was higher compared to that of the vegetated gravel bed. This is attributable to the fecal coliform partitioning in the total suspended solids of which better removal was observed in the unvegetated cell.

The typical removal efficiencies obtained in the gravel beds during the course of the study (> 99.9%) are only comparable to those reported for activated sludge systems and stabilization ponds. The wetland system however, have the advantage of low investment and operating cost, and hence a viable alternative system of wastewater treatment.

Filtration, which is not entirely time dependent, was the main mechanism responsible for the removal of suspended solids as depicted in Fig 5. (a-c). Removal of this pollutant was significant as far as secondary treatment of domestic wastewater. The analysis done for TSS loading rate gave values of 122 $KgHa^{-1}day^{-1}$. This highlights the potential of subsurface horizontal flow constructed wetlands to polish pretreated wastewater with minimum area (land) requirements in the tropics.

Conclusion

Subsurface horizontal flow constructed wetland systems can effectively remove Fecal coliform and total suspended solids in pretreated domestic wastewater under the tropics conditions.

The empirical relationships developed in this study can be used in the rational design of subsurface wetlands for conditions similar to the ones under which this study was conducted. More work needs to be undertaken to establish scale related relationships and confirming the likely maintenance schedule for the wetlands.

Acknowledgment

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