Potential of Constructed Wetlands as an Alternative for Wastewater Treatment to Meet Standards for Reclamation and Re-Use in Agriculture

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Abstract

This research was carried out to assess the performance of the Horizontal Sub-Surface Flow Constructed Wetland (HSSFCW) system in polishing pre-treated wastewater in the Upward Flow Anaerobic Sludge Blanket (UASB) reactor plant as a potential wastewater treatment system that can meet the requirement for wastewater recycling and re-use for agricultural purposes. The HSSFCW unit was designed and operated with a hydraulic loading of approximately 0.1m^3/m^2/day and a hydraulic retention time of approximately four days, and it was packed with fine gravel and sand with an average porosity of 48%. Faecal Coliforms in the effluent which was in the magnitude of 7 log units, was reduced to 3 log units, while the mean Biological Oxygen demad (BOD$_5$) in the final effluent was observed to be 5.6 mg/l. These values meets the required removal efficiency recommended by World Health Organisation (WHO), Food and Agricultural organisation (FAO), and Tanzanian standards for wastewater re-use in irrigation suggesting, therefore, that the HSSFCW has potential and can be applied in the reclamation of wastewater for irrigation to benefit the society in tems of crop yields.

Key words: Wastewater treatment, agricultural use, constructed wetland, re-use

Introduction

Reclaimed wastewater is a proven reliable source of water for various uses in many regions of the world. According to Gearheart *et al.*, (1999), wastewater re-use in agriculture has been practised throughout the world with the objective of converting wastewater into a usable resource for environmental protection and sustainable development. Jimenez *et al.*, (1999) reported on the use of wastewater from Mexico City since 1890 to irrigate an important agricultural area of about 90.000 ha, resulting in significant increases in the crop yields. The conventional technologies available for treating domestic wastewater to levels acceptable for recycling and use for agricultural purposes have proven to be expensive both to construct and to operate (USEPA. 1998). Accordingly, the cost of these technologies both in terms of construction and operation are prohibitive to all but the large and more affluent communities. This is especially because the benefits in terms of crop yields where wastewater is used requires that any treatment employed reduces only partially the nitrogen, phosphorus and organic matter present in wastewater. On the other hand conventional treatment reduces the levels of these parameters to very low ones.

In recent years, numerous studies have investigated the use of Constructed Wetlands (CW) for the treatment of wastewater (Vymazal *et al.*: 1998. Green *et al.*, 1997 and Kadlec and Knight. 1996). These studies have demonstrated

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that CW can reliably and efficiently treat domestic wastewater to meet the required standards for re-use in agriculture and horticulture. CW are engineered systems that have been designed and constructed to imitate the natural wetlands by utilising the natural processes involving wetland vegetation, soils and the associated microbial assemblages (Vymazal, 1998). They can be built with a much greater degree of control, thus allowing the establishment of a well-defined composition of substrate, type of vegetation and flow pattern. In addition CW offer several other advantages over the natural wetlands, including site selection, flexibility in sizing and control over the hydraulic pathway and the retention time. They are designed to take advantage of many of the processes that occur in natural wetlands, but they do so within a more controlled environment. According to Spiels and Mitch (2000), CW can be suitably used as primary means, as integrated secondary and tertiary treatment, general tertiary treatment or for specific tertiary treatment.

lease nitrogen compounds during transpiration. Percolation and lateral water movement may also remove nutrients. For wastewater treatment, the resulting bio-mass has to be harvested so that the accumulated nutrients are removed completely from the system. Vymazal *et al.*, (1998) reported that pollutants in CW systems are removed through a combination of physical, chemical and biological processes including sedimentation, precipitation and adsorption to soil particles, assimilation by plant tissues and microbial transformations.

The aim of this paper is to report the findings of a study on the use of a Horizontal Sub-Surface Flow constructed Wetland (HSSFCW) to treat domestic wastewater to meet requirements for wastewater recycle and re-use in agriculture (irrigation). In the study, the perfomance of the HSSFCW to polish the anaerobically pre-treated domestic wastewater in the Upflow Anaerobic Sludge Blanket (UASB) pre-treatment reactor plant in the removal of Faecal Coliforms (FC),

Table 1: Design standards and parameters for HSSFCW pilot plant

Design parameter	Adopted design value
Influent BOD_5 to the HSSFCW (Co)	90 mg/l
Desired effluent BOD_5, from HSSFCW (Ce)	10 mg/l
Minimum temperature of wastewater to be treated	26°C
Average flow rate from UASB to HSSFCW, Q_d	0.5 m³/day

Volatile Suspended Solids (VSS) and Biological Oxygen Demand (BOD) were studied.

The wastewater treatment mechanism in the CW systems involves aquatic plants, which in several processes cycle and remove nutrients from the wastewater. According to Rivera *et al.*, (1995), in the wetland removal mechanisms, atmospheric carbon is fixed via photosynthesis while the growing plants assimilate nutrients e.g. Nitrogen, Phosphorus and Potassium from sediments and the water column. Nutrient-containing bio-mass can be harvested and removed or it can die and decay, providing food for detritus consumers and leaving the hard matter to decompose into humus for burial in sediments. Organic carbon from plants serves as an energy source for Nitrogen fixation and denitrification. Nutrients are released to the water column by leaching from plants and detritus. They are also exchanged between the water column and sediments. Emergent plants may re-

Materials and methods

Site description

A HSSFCW field scale pilot plant was built at a site located at the University College of Lands and Architectural Studies (UCLAS), about 12 km North of Dar es Salaam city, at an altitude of approximately 60 metres above mean sea level. The weather condition of this area is basically a tropical coastal climate. The average yearly temperature varies from 23 °C to 28 °C and annual precipitation ranges between 500 mm to 1000 mm, while the absolute humidity is between 67 % to 96%. Within the site, there is an existing Upward Anaerobic Sludge Blanket (UASB) reactor plant. which is meant for research work on domestic wastewater treatment. Part of the domestic wastewater from the students' hostel was diverted to the UASB for pre-treatment prior to discharge into the HSSFCW

Design of HSSFCW units

The design parameters for the HSSFCW in this study were based on the characteristics of the wastewater effluent from the UASB and the desired effluent quality from the HSSFCW units. The adopted average influent BOD_5 value to the HSSFCW from the UASB plant was 90 mg/l. The desired effluent BOD_5, from HSSFCW was adopted in accordance with the WHO standards and Tanzanian temporary standards recommendations for restricted wastewater re-use in irrigation. The design standards adopted are provided in Table 1.

From the design perspective. the problem of HSSFCW is to determine the surface area of the treatment cell needed to achieve specified removal efficiency. According to Buchberger and Shaw (1995), HSSFCW are assumed to be attached growth biological plug flow reactors operating with first order kinetics. The following governing equation for BOD removal was used in the design of HSSFCW.

$$C_e = C_i \exp(-Kt) \qquad (1)$$

Where C_i and C_e represent influent and effluent BOD_5 (mgl^{-1}). K is the temperature dependent rate constant ($days^{-1}$) and t is the HSSFCW hydraulic retention time (days). The temperature dependent rate constant K is normally obtained from equation (2).

$$K = k_{20}(1.06)^{(T-20)} \qquad (2)$$

Where k_{20} is the rate constant ($days^{-1}$) at 20 °C and T is the wastewater temperature (°C). Kadlecand Knight (1996) have reported that k_{20} in HSSFCW ~ 1.10 ($days^{-1}$).

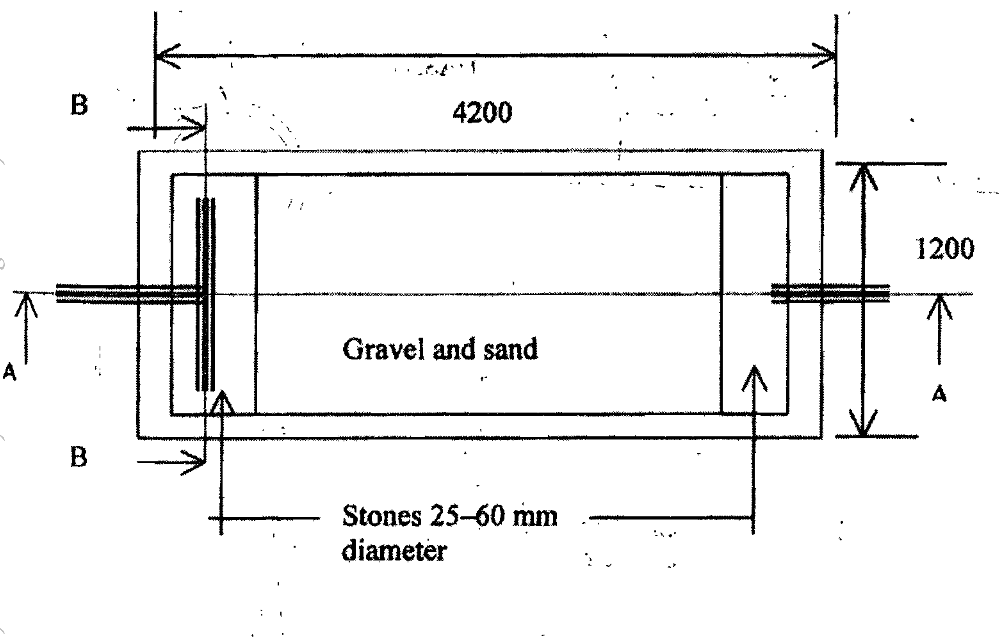
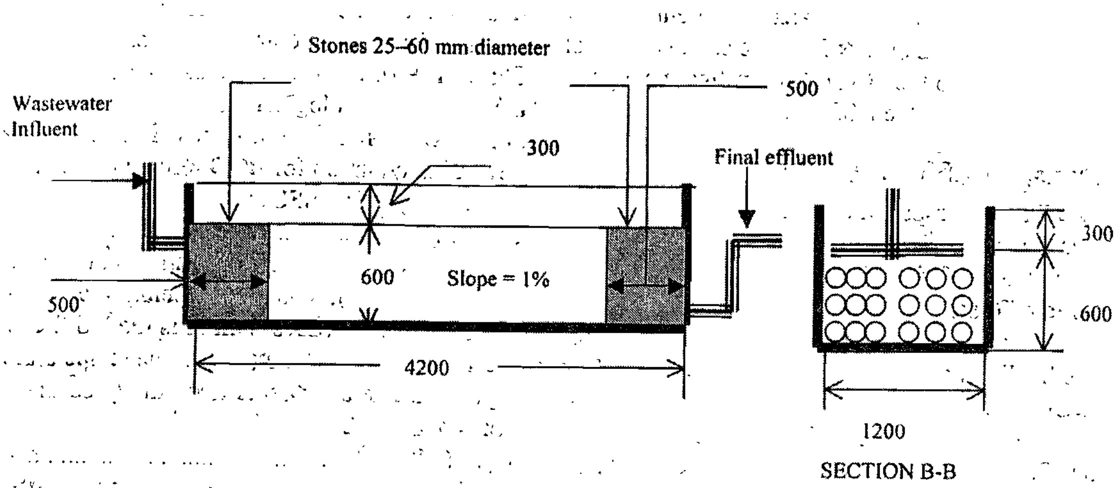


Figure 1(a): Schematic plan of a HSSCW unit



(b): Schematic cross - section of a HSSFCW unit

Experimental set up

The experimental set up that was used is shown in Figure 2. A UASB and HSSFCW wastewater flow arrangement in which the HSSFCW unit was planted with *Typha latifolia* and packed with gravel (varying between 3 mm to 6 mm diameter) and sand was studied.

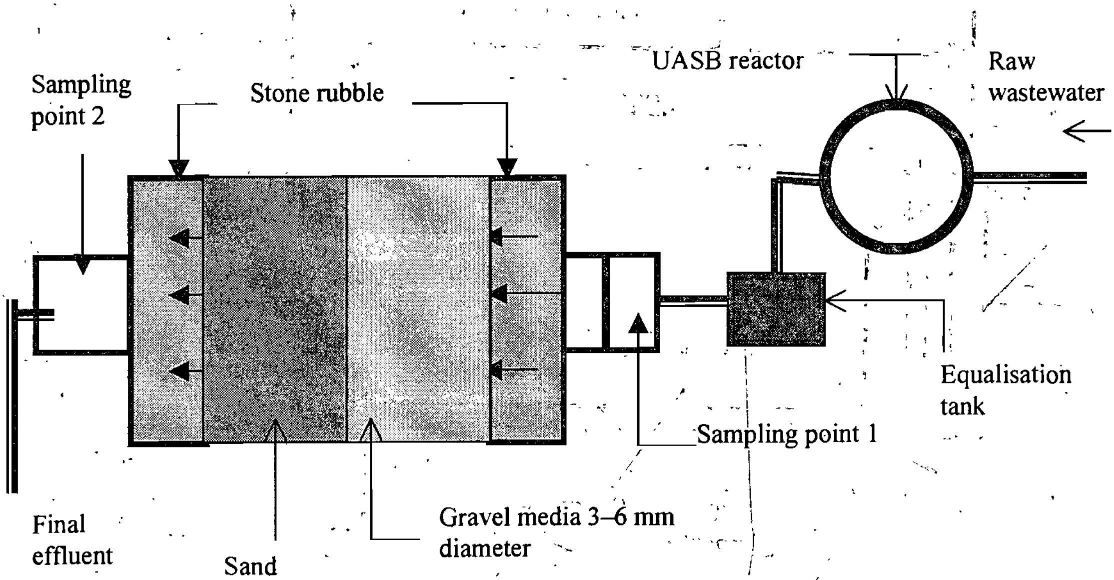


Figure 2(a): Schematic presentation of the experimental set up (plan)

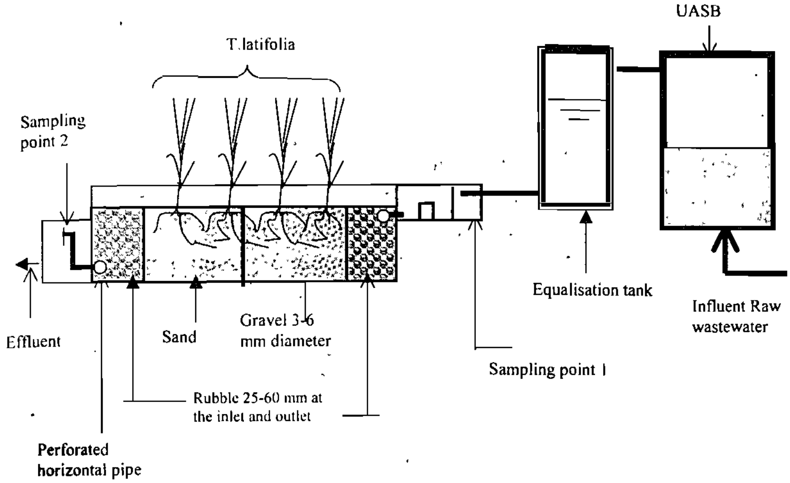


Figure 2(b): Schematic cross -section of the experimental set-up

An average value of substrate porosity (p) of 48 % was experimentally established for the two filter media (gravel and sand) based on the relatioship :

$p(\%) = (pd - bd)*100$ ....(3)

Where bd is the bulk density of gravel calculated as the ratio of dry weight of the gravel sample to its volume, pd is particle density calculated as the ratio of the dry weight gravel sample to the difference of volume of the gavel and the volume of waste required to replace the pores.

The hydraulic retention time t (days) was established based on the following equation:

$t = \frac{phlw}{q}$ ....(4)

Where p is the porosity of the substrate media, q is mean flow rate (m^3/day), l (m) and w (m) are length and width of the HSSFCW, respectively, and h (m) is the effective depth of the HSSFCW.

Monitoring and sampling procedures

The initial sampling started after five months of wetland plant growth as recommended (Billore *et al.* 1999). This is because CW typically requires a few months for vegetation and bio-film establishment. In this study, within four months CW plants covered the whole effective area in the HSSFCW.

Wastewater influent and effluent from the HSSFCW were monitored and recorded daily for a period of 3 months between November, 2001 and January, 2002 and mean values obtained.

Wastewater samples were collected for analysis from points 1 and 2 twice a week. These samples were analysed in the laboratory for FC, BOD and Volatile Suspended Solids (VSS). The VSS were analysed in order to evaluate the population of bacteria in the HSSFCW as recommended by Esoy *et al.*, (1997), Henze *et al.*, (1996) and Valentini *et al.*, (1997). This is because VSS are made up of volatiles associated with biological growth in wastewater treatment plants. The FC are indicator organisms that were analysed as per WHO recommendations (WHO. 1989) and are of particular significance because in the field of bacteriological analysis of wastewater, their occurrence has traditionally been regarded to be of special interest from a public-health perspective, since these organisms are a regular component of the intestinal fauna of mammals. Green *et al.*, (1997) reported that successful removal of indicator organisms is a sufficient guide to the removal of more serious pathogenic organisms from the water. Kadlec and Knight (1996) also reported that direct measurement of some pathogenic bacteria provides results similar to measurement of indicator bacteria species. The BOD is a measure of the oxygen consumption of micro-organisms in the oxidation of organic matter. It is measured as the oxygen consumption in an air tight incubation of the sample. This test normally runs for 5 days, and the result is then more properly designated as BOD_5.

In this study, all analyses were carried out in accordance with The Standard Methods of Examination of Water and Wastewater (APHA.1992).

Results and discussion

Removal of BOD and VSS

Results obtained in this study indicated that the BOD_5 influent range in the HSSFCW was between 130.0 and 86.0 mg/l. with an average value of 107.4 ± 6.0 (n = 18) at 95 % confidence interval. The effluent range was between 9.0 and 3.0 mg/l, with an average value of 5.6 ± 0.7. which represented an average removal of 94.5 % ± 0.5 at 95 % confidence interval. Figure 3 presents the influent and effluent BOD_5 variation during the period of the study.

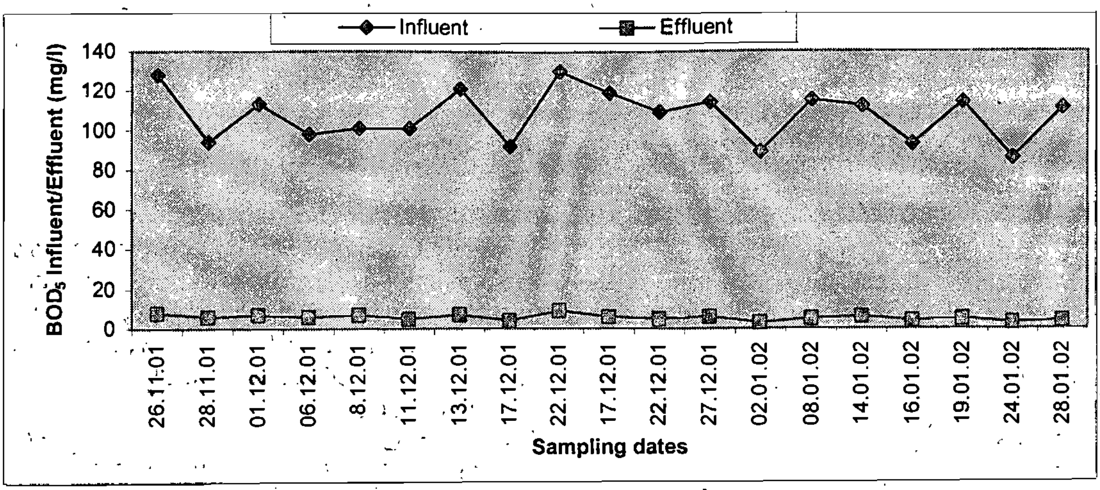


Figure 3: BOD influent and effluent variation in the HSSFCW system

The VSS influent varied between 110.0–320.0 mg/l with an average value of 211.9 ± 23 (n = 29), while the effluent range was between 4.0 and 24.0 mg/l with an average value of 12.9 ± 0.2 at 95 % confidence interval as shown in Table 2. Figure 4 indicates the variation of VSS influent and effluent in the HSSFCW.

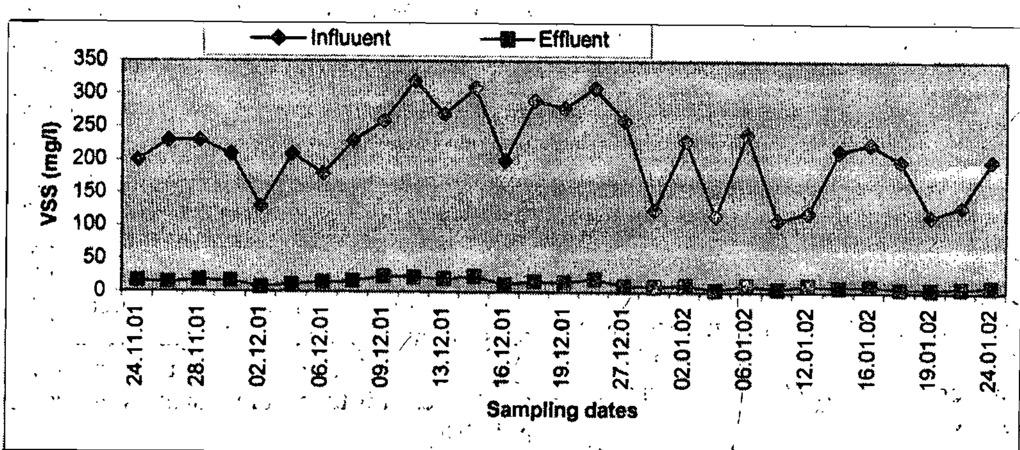


Figure 4: Influent and effluent VSS (mg/l) in the HSSFCW system

Table 2: BOD influent and effluent ranges and percentage removal in the HSSFCW

Parameter	Influent		Influent		% Removal	
	Range	Average	Range	Average	Range	Average
BOD_5 (mg/1)	130 - 86	107.4 ± 6.0(n=18)	9-3	5.6 ± 0.7	96.6 - 93.1	94.5 ±0.5
TSS	110.0 -320.0	211.9 ± 23 (n=29)	4-24	12.9 ±0.2	91.0 - 97.0	94.0 ±0.6

The BOD_5 final effluent quality obtained in this study (5.6 mg/l) was better compared to those obtained in a similar study (Kaseva, 2002). This observation indicate that the HSSFCW is capable of complementing the BOD removal and. thus. complied with the Water Utilisation (Control and Regulation) (Amendment) Act (1981) requirement for wastewater disposal in receiving water bodies (30 mg/l) as well as the requirements for re-use in irrigation and horticulture (10 mg/l). These results suggests that fine gravel particles are suitable for better pollutant removal compared to coarse ones as reported by Kaseva (2002). probably due to the effect of increased surface area for attachment of microbial community responsible for effective polishing of the wastewater (Sousa *et al.*, 2001). Green *et al.*, (1997) also reported that fine substrate media resulted in rapid staining, attachment and accumulation of solids and thus rapid pollutant removal in the CW systems. A relatively higher hydraulic retention time of 3 days compared to that reported by Kaseva (2002) might also have contributed to the enhanced performance.

Removal of FC

The FC influent was in the magnitude of 7 log units ranging between 21 x 10^6 and 11 x 10^6 FC/100ml while the effluent were in the magnitude of 3 log units (4 logs units removal) ranging between 1.3 x 10^3 and 0.3 x 10^3 FC/100ml. Figure 5 presents the influent and effluent FC concentration (FC/100ml) variations (n = 29). while the average influent and effluent FC concentration values for samples collected between November. 2001 and January 2002 in the HSSFCW were as shown in Figure 6.

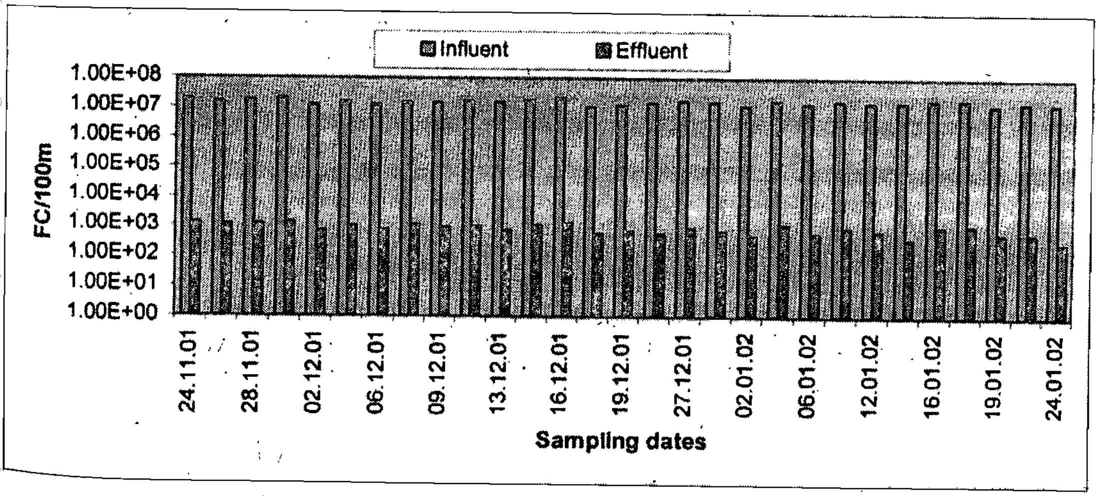


Figure 5: **FC influent and effluent variations in the HSSFCW system**

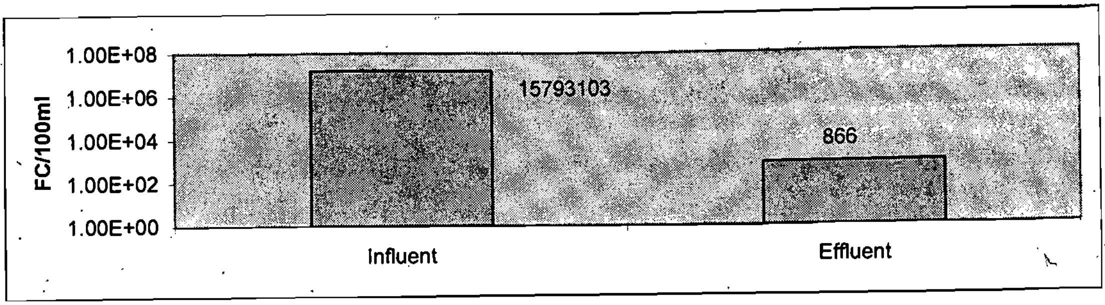


Figure 6: Average FC concentration (FC/100 ml) in the HSSFCW system

The HSSFCW showed a high efficiency (99.99 %) in the removal of FC, which may be attributed to physical, (filtration, adsorption), chemical (oxidation) and biological (production of antibiotics) processes induced by the presence of the wetland plants, as reported by Sousa *et al.*. (2001), Rivera *et al.*, (1995) and Khatiwada and Polprasert (1999). The high removal of FC is likely to have been contributed by the large surface area for attachment of the microbial community due to fine gravel in the first half of the HSSFCW and sand media in the other half. Vymazal (1998) also reported that wastewater purification efficiency was strongly dependent on the hydraulic characteristics of the bed media, which had a pronounced influence on the performance of CW systems. The results obtained over a hydraulic retention time of 3 days in this study are better than those reported by Kiwanuka and Kelderman, (2001), where a removal of 99.9 % was obtained in a hydraulic retention time of 7 days. This confirms the influence of size of the media on the performance of CW through hydraulic retention time. Further studies, however, need to be carried out to determine, and perhaps avoid the likelihood that the system would clog if operated for extended periods of time. Results obtained in this study suggest that the wastewater effluent met the required guidelines (FAO 1997: WHO 1989) and can be recycled for re-use in irrigation and horticulture.

BOD_5 and FC results in comparison with various recommended standards

The obtained BOD and FC results were compared with the World Health Organisation (WHO), United Nations Food and Agriculture Organisation (FAO) standards and the Tanzanian recommended values for wastewater re-use in irrigation. The revised WHO guidelines for wastewater re-use in agriculture and horticulture specifies that the FC concentration in the effluent should be less than 1000 per 100 ml (WHO, 1989). Similar guidelines have also been recommended by FAO in a report on quality control of wastewater for irrigated crop production (FAO, 1997), while the World Bank general guidelines have recommended coliform counts of less than 400 MPN/100 ml for wastewater reuse in irrigation. The recommended BOD_5 guidelines for wastewater re-use in irrigation in the US vary between 30-150 mg/l, depending on the type of irrigation (USEPA, 1988). In Tanzania, the Water Utilisation (Control and Regulation) (Amendment) Act (1981) has recommended 10 mg/l BOD_5 for wastewater which is suitable for re-cycling and re-use in irrigation and other industrial activities, and between 30 to 40 mg/l BOD_5 effluent for direct discharge into receiving water bodies.

Conclusions

This study dwelt on the investigation of the capacity of a HSSFCW system in providing final effluent quality. The experimental set up consited of the UASB-HSSFCW packed with fine gravel and sand media and planted with *T. latifolia*. Results from this study (HSSFCW operated with hydraulic loading of approximatelt 0.1 m^3/m^2/day and a hydraulic retention time of about 4 days) show that the FC removal was from the order of 10^7 per 100 ml to FC<10^3 which represents 99.99% removal. while the mean BOD_5 in the final effluent was observed to be 5.6 mg/l which is about 94.5% removal. These results meet the required removal efficiency recommended by WHO (1989), FAO, (1997) and Tanzanian standards (The Water Utilisation (Control and Regulation) (Amendment) Act (1981) for wastewater re-use in irrigation. This suggest that CW is a technology which can be used to treat wastewater to levels that can allow it to be recycled and re-used for agricultural purposes.

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