Wat. Res. Vol. 34, No. 4, pp. 1135–1144, 2000

Printed in Great Britain
0043-1354/00/$ - see front matter

PII: S0043-1354(99)00238-9

PERGAMON
www.elsevier.com/locate/watres

CONSTRUCTED WETLAND AT THE UNIVERSITY OF DAR ES SALAAM

D. A. MASHAURI*, D. M. M. MULUNGU and B. S. ABDULHUSSEIN
University of Dar es Salaam, Water Resources Engineering Programme, PO Box 35131, Dar Es Salaam, Tanzania

(First received 1 November 1998; accepted in revised form 1 May 1999)

Abstract—Following lack of investment in wastewater treatment, high investment and maintenance cost, conventional treatment systems have not been used in Tanzania. On the other hand, cost effective wastewater treatment methods like the use of septic tanks, soak pits, drainage fields and waste stabilization ponds are widely applied. One of the methods of achieving compliance using conventional treatment systems at low cost, producing treated water pollution free and fostering a community responsibility for wastewater treatment involves the use of natural or constructed wetlands. To date, no wetlands have been used for treating wastewater in Tanzania. Therefore in an attempt to promote the use of constructed wetland for wastewater treatment, a horizontal flow constructed wetland at the University of Dar es Salaam was commissioned for treatment of wastewater effluent from the University waste stabilization ponds (WSP).

This paper presents results obtained from a constructed wetland (CW) installed at an outlet of the WSP of the University of Dar es Salaam. The field tests were conducted at low and high filtration rates 0.27 m/h and 2.3 m/h respectively for a period of 4 weeks. Treatment effectiveness was evaluated which indicated high mean removal efficiencies; 80% for SS, 66% for COD, 91% for faecal coliforms (FC) and 90% for total coliforms (TC) achieved at the low filtration rate. Thus, wetlands if properly designed, operated and maintained can provide an efficient and economical means of upgrading the quality of secondary treated wastewater to an acceptable level. © 2000 Elsevier Science Ltd. All rights reserved

Key words—constructed wetland, pollution control, domestic wastewater, horizontal sub-surface flow system, emergent plants, *Typha latifolia*

INTRODUCTION

There are many definitions of wetlands which have been accepted worldwide suiting a particular study. The International Conference on Wetland Systems for Water Pollution Control held in Vienna on the 19th of September, 1996, defined constructed wetlands as 'any setup that has been realised by human interference in order to treat wastewater and that is inhabited by plants' (Makerere University, 1997). For the purpose of this research, this definition is adopted.

Wetlands in Tanzania cover over 7% of the country's surface area as cited by Bakobi (1993). This includes large inland water bodies such as Lake Tanganyika in the west, Lake Victoria in the north-west, Lake Nyasa in the south and Lake Rukwa in the south-west as well as territorial waters off the Indian Ocean coast. There are a variety of other small lakes, swamps and flood plains which altogether form a major wetland resource. Generally wetland ecosystems have great functional diversity. In Tanzania, the productive nature of these ecosystems has not been valued and they have been threatened by development. Some of these natural wetlands are either affected by industrial pollution (e.g. Msimbazi–Dar es Salaam), have been earthfilled and houses built on or converted to agricultural land.

Although the ministry in charge of environmental issues has important roles of coordinating, planning and implementing, the prime responsibility for environmental management rests on many different people and agencies. For example, if a wetland falls within a national park or game reserve, then its management is under the director of wildlife. Wetlands within the protected areas are controlled by the protecting authority. Hence the management and conservation of wetlands is the responsibility of all sectors that use or possess them.

Wetlands, either natural or artificial (constructed), have a substantial capacity for wastewater treatment or renovation (Venus, 1987). The process involves the use of existing or planted root system of reeds (elephant grass, *Typha latifolia*, etc.) so

*Author to whom all correspondence should be addressed. Fax: +225-51-410029; e-mail: head_ce@ce.udsn.ac.tz

that the plants survive on the nutrients in the wastewater (Finlayson and Moses, 1991). Since aquatic plants have a natural mechanism for pumping air via their root system, the root area provides an oxygen-rich environment which supports a range of aerobic bacteria similar to those found in other sewage treatment processes (Loveridge *et al.*, 1995). This involves many different physical, chemical and biological processes. They include sedimentation, precipitation, adsortion to soil particles, assimilation by the plant tissue and microbial activity. Numerous systems have been developed since the initial research into constructed wetlands in the 1960 s.

From an inventory survey on natural and constructed wetlands conducted for companies and factories in Tanzania, it was revealed that the use of wetlands as a recipient of wastewater had not been realised. The dominant means of wastewater treatment was found to be the use of septic tanks, soak pits, drainage fields and waste stabilization ponds (Mulungu and Mashauri, 1997). This is due to the fact that as a result of lack of investment in wastewater treatment, high investment and maintenance cost, conventional treatment systems have not been used in Tanzania. One of the methods of achieving compliance using conventional treatment systems at low cost, producing treated water pollution free and fostering a community responsibility for wastewater treatment involves the use of natural or constructed wetlands.

The University of Dar es Salaam (UDSM) has one wastewater treatment plant into which most of the wastewater from University community goes. The treatment of wastewater is carried out by natural process using WSPs. These ponds serve most of the University population. The University waste stabilization ponds consists of seven ponds, one primary facultative pond and six maturation ponds. The primary facultative pond is in series arrangement with parallel series of two facultative ponds and one maturation pond. The effluent from the maturation pond is then discharged into a nearby stream. Because of the re-use potential of WSP effluent for agricultural and ground water recharge, then the need for further treatment of the effluent has been realised.

This paper summarizes a study on constructed wetland at the University of Dar es Salaam which examines the role of constructed wetland (reed bed filter) not only for upgrading the quality of secondary treated wastewater (WSP effluent) but also for providing an efficient and economical means of treating such wastewater.

MATERIALS AND METHODS

The study site is located at the premises of the University of Dar es Salaam WSP (Fig. 1). Downstream of the WSPs is where the constructed wetland is built. There are two major flow systems: the horizontal-flow system and the vertical-flow system. The former has two main types of flow system design: surface-flow system and sub-surface flow system. The horizontal sub-surface flow has been adopted because of its higher efficiency and more sanitary environment (Fig. 2). Channel design and construction play crucial roles in the successful performance of the system (Boon, 1986). This includes choice of the reed, substrate material and correct channel gradient for satisfactory hydraulic flow. Other factors of prime importance are the climate and temperature of the location for metabolic activity in microorganisms residing in the beds and the quality of treatment required to be achieved.

The design data of the reed bed treatment system involved the filtration rate and the feature of the reed bed system. Controlling filtration rate is the key to adequate functioning of a reed bed. Since no proper design guidelines were available, the filtration rate assumed was 0.27 m/h and 2.3 m/h. The flow rates were maintained for weeks. This was adopted randomly to investigate the treatment efficiencies at low and high filtration rates. The filtration rate was measured by adopting the principle that the flow over a weir in an open channel is related to the depth of the water above the crest of the weir. A predetermined filtration rate was first selected and the flow through the

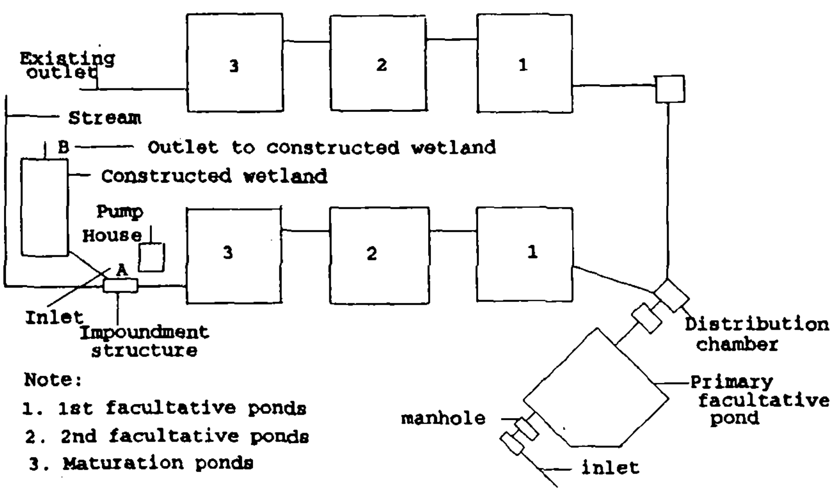

Fig. 1. Location of University of Dar es Salaam WSPs and the constructed wetland.

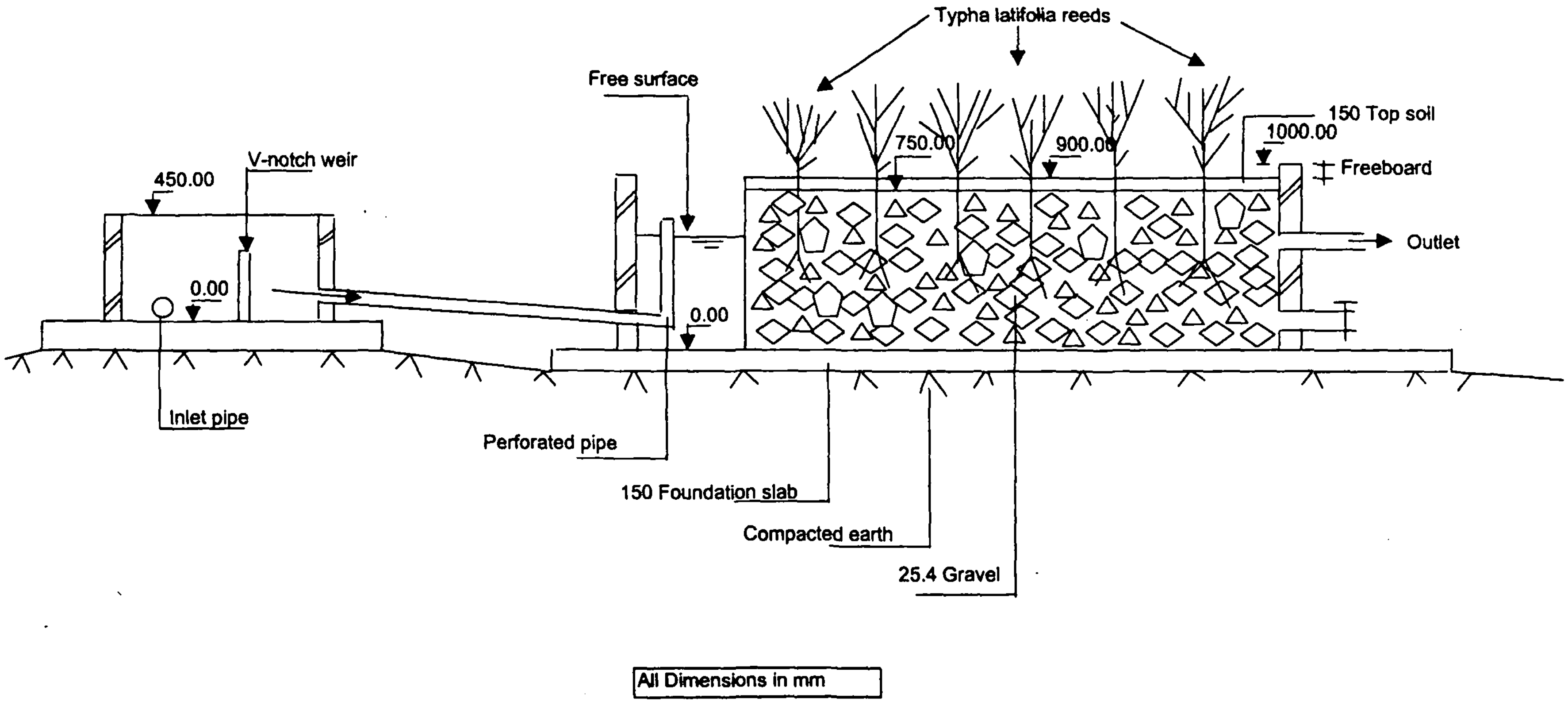

Fig. 2. Vertical section through the constructed wetland.

channel was then computed using equation (1)

$$Q = V_f A \quad (1)$$

where, Q is flow in m^3/h, V_f is the predetermined filtration rate in m/h and A is effective cross-sectional area of the channel.

The depth of flow over the weir that would give that flow was obtained by the calibrated equation (2) below.

$$Q = \frac{8}{15} C_d (2g)^{1/2} \tan\frac{\theta}{2} H^{5/2} \quad (2)$$

where, Q is discharge in m^3/s, C_d is coefficient of discharge (0.6), θ is angle of V-notch weir (30°), H is the height of the water above the vertex of the weir in m and g is the accelaration due to gravity (9.8 m/s^2).

The main features of the reed bed considered are: reed bed channel filter media/substrate (aggregates) and reeds, inlet and outlet and flow measurement device. A wide range of gravel-based systems have sizes ranging from 1 mm to 25 mm have been used, and the sewage retention times are usually hours rather than days as for soil-based systems (Loveridge *et al.*, 1995). The reed bed (5 × 1 × 1 m) consisted of a concrete channel 100 mm thick, aggregates (1 in) obtained from sieve analysis which will not be prone to clogging and resist flow through the bed. The grain size of the rock material used had an effective diameter (d_{10}), 21.24 mm, and a uniform coefficient (U_c), 1.49 which were derived from the particle size distribution. The aggregates were soaked and washed thoroughly prior to placing into the channel to remove suspended solids and organic matter. The *Typha latifolia* reeds were planted on the soil with the substrate material (aggregates) placed below in grids measuring 20 × 20 cm. The soil is top soil composed of clay and humus materials. The reed bed was walled with sand-cement blocks and then rendered both internally and externally with cement mortar. The rate of filtration was set with the inlet valve. Once the desired rate was reached, no further manipulation of the valve was required. At first the water level over the reed was low but it rose gradually to compensate for the increasing resistance of the substrate material. Flow measurements were determined by the 30° steel V-notch weir.

A 4 week monitoring programme was carried out three months after commissioning and start up of the system. The monitoring programme was done from April to May, which is the wet season in Dar es Salaam. The corresponding mean rainfall was 7.4 mm/d and 4.3 mm/d for April and May 1997, respectively. Due to the wet season, the growth and decay of the plant material was very high. Sampling points were provided to monitor the quality of water at the inlet and outlet. The samples to be analysed were taken from two different points of the reed bed treatment system; the inlet point A which is the effluent from the maturation pond where a grab sample of water was taken and the outlet point B which consisted of the filtrate from the bed (Fig. 1). Samples were taken between 10:00–11:30 h at intervals of a few days. Samples were then taken to the University laboratory for analysis according to standard methods. The parameters investigated during this study were classified into three groups namely: physical, chemical and bacteriological tests.

Physical wastewater quality parameters were temperature, turbidity, colour, conductivity, suspended solids (SS) and total dissolved solids (TDS). Chemical wastewater quality parameters were pH, dissolved oxygen (DO), biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD). Bacteriological wastewater quality parameters were total coliforms (TC) and faecal coliforms (FC). Conductivity and temperature were measured using HACH Conductivity/TDS meter model No. 44600, total solids (TS) includes both SS and TDS was measured by filtering through a standard glass fiber filter, colour was determined with the aid of a DR 2000 Spectrophotometer, turbidity was determined with the aid of a DR 2000 Spectrophotometer and the procedure calibrated using Formazin Turbidity Standards giving readings in terms of Formazin Turbidity Units (FTU).

The pH value was measured with a model WTW 523 pH-meter and the test carried out according to the Standard Method for the Examination of Water and Wastewater (APHA/AWWA/WPCF, 1992). Dissolved Oxygen being one of the most important analyses in determining the quality of the biological activity in the reed bed filter, was measured using a WTW DO meter model No. 1910338 according to the Standard Method for the Examination of Water and Wastewater (APHA/AWWA/WPCF, 1992). COD as a measure of organic strength of wastewater was determined by Closed Reflux, Titrimetric method. BOD was determined by measuring the amount of oxygen absorbed by a sample of wastewater in the presence of microorganisms in 5 days at a temperature of 20°C. This was accomplished by membrane filtration technique. For bacteriological parameters, coliforms were useful indicators of pollution and provided presumptive evidence of the presence of pathogens both bacterial and viral. It was not possible to measure all parameters because of unavailability of some apparatus and reagents at the laboratory especially for parameters such as COD, BOD_5, total nitrates and total ammonia.

RESULTS

From the four weeks monitoring programme carried out, 4–7 samples were collected and analysed for each of the parameters. Table 1 gives the summary of the average parameters for physical, chemical and bacteriological qualities, for the two phases under investigation (Abdulhussein, 1997). Phase one (P1) is at a low filtration rate (0.27 m/h) and phase two (P2) is at a high filtration rate (2.3 m/h). The values given are the average indicators of the constructed wetland treatment effectiveness. Due to the break down of the incubator for the measurement of BOD_5 value during this study, it was not possible to get enough values to make an analysis.

Table 1. Average indicators of the treatment effectiveness in the constructed wetland[a]

Indicator	Phase 1 (P1)		Phase 2 (P2)	
	Inlet	Outlet	Inlet	Outlet
Temperature (°C)	26.00	25.30	26.40	25.90
Turbidity, FTU	102.50	43.00	98.60	61.00
Colour, PtCo units	464.67	212.83	477.80	303.40
Conductivity (μs/cm)	432	454	358	390
SS (mg/l)	104.80	21.20	101.80	51.00
TDS (mg/l)	178	194	158	170
pH value	8.73	7.81	9.54	9.15
DO (mg/l)	4.16	1.08	6.5	3.02
COD (mg/l)	100.75	34.50	125.75	62.25
TC (Nos/100 ml)	60,000	5850	71,250	51,500
FC (Nos/100 ml)	48,250	4525	62,000	41000

[a]In general, the constructed wetland showed a sufficient removal efficiency with respect to Turbidity, Colour, SS, DO, COD, TC and FC at low filtration rate as presented in Table 2. This is due to the fact that, at a high filtration rate, the retention time is small and wastewater leaves early before perfect treatment is achieved.

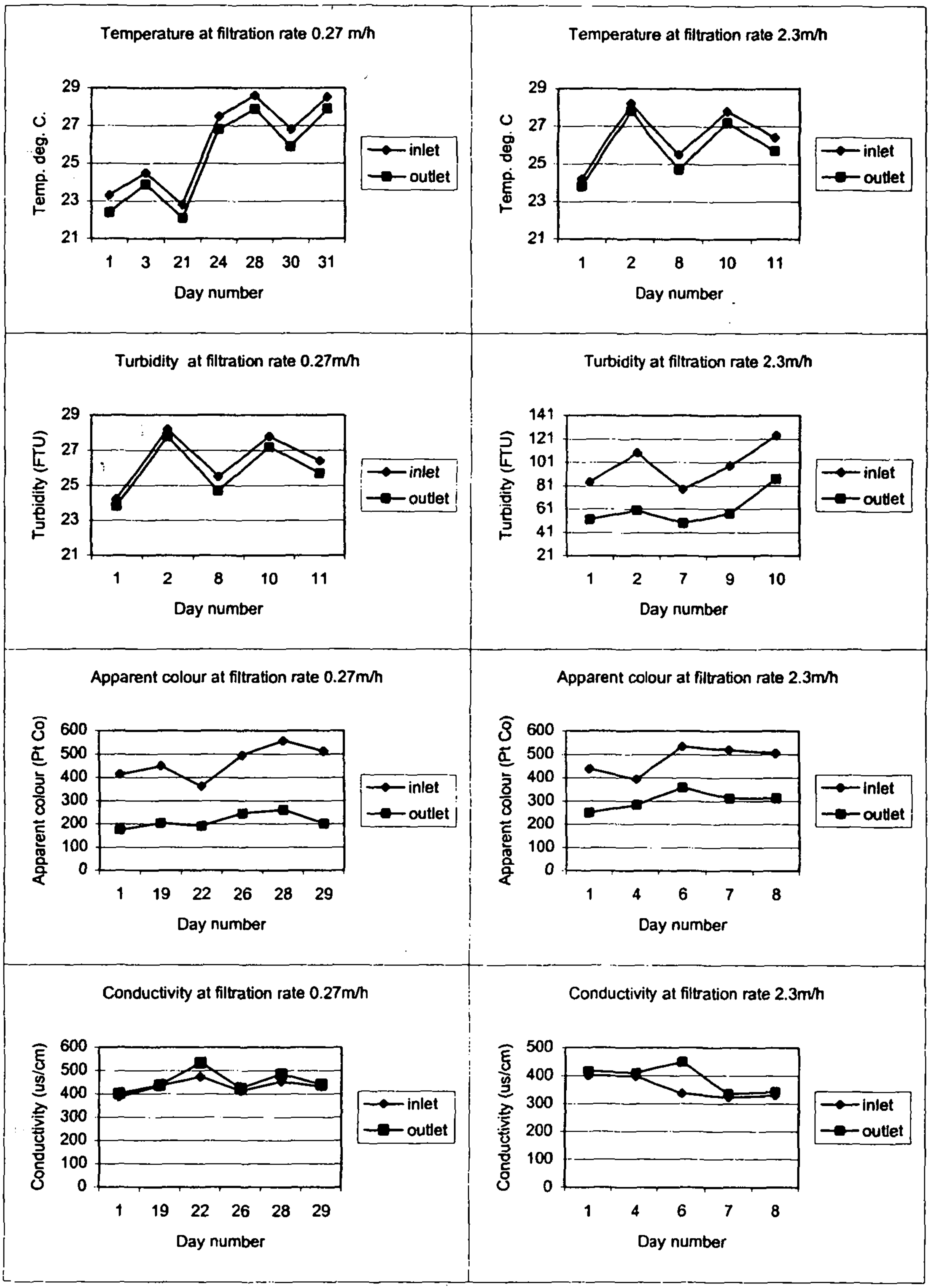

Fig. 3. Time variation of wastewater quality for the inlet and outlet.

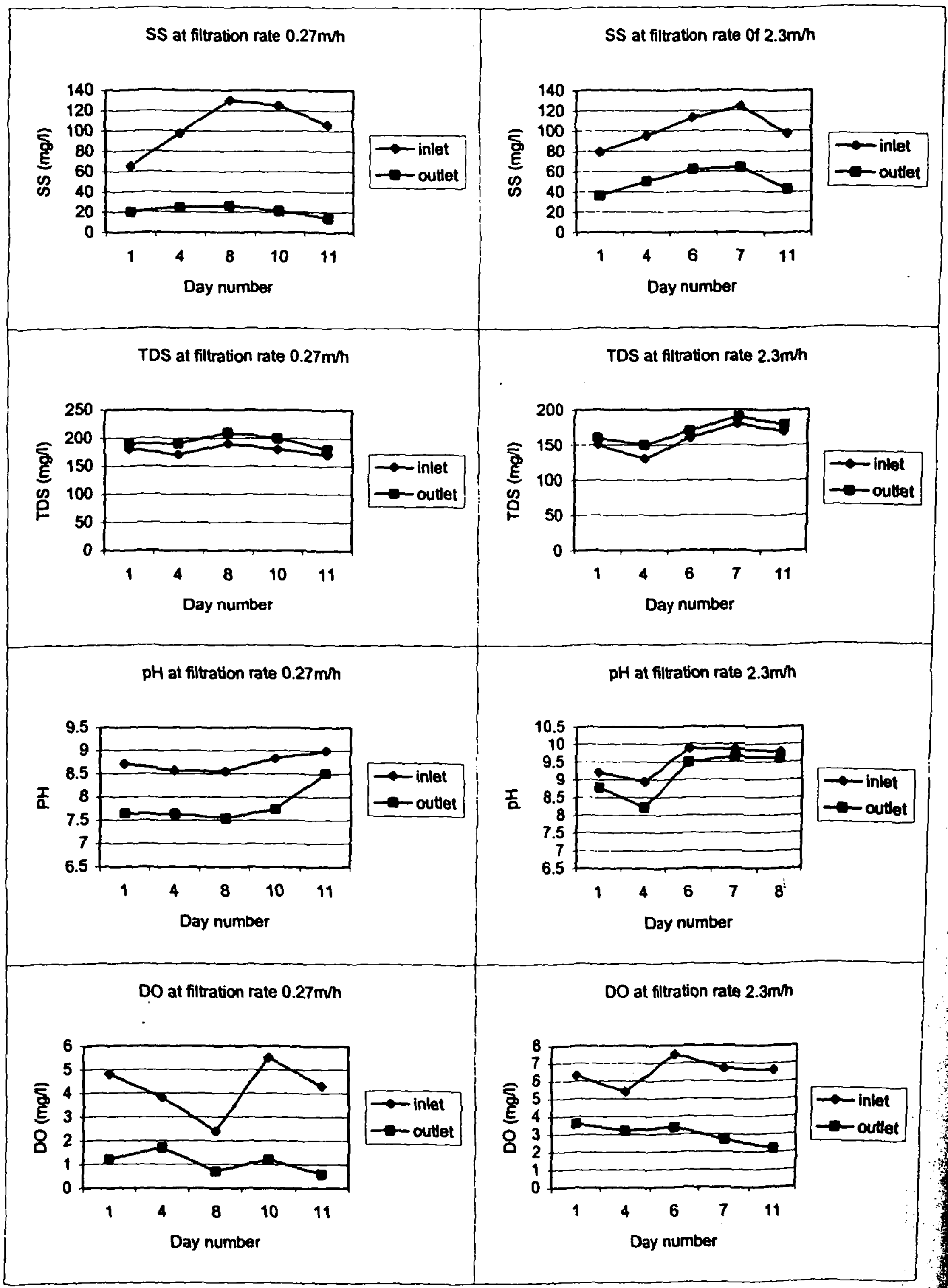

Fig. 4. Time variation of wastewater quality for the inlet and outlet.

Th
inlet
gives
struct

Table

Indicat

Turbidi
Appare
Suspenc
Dissolv
Chemic
Total C
Faecal

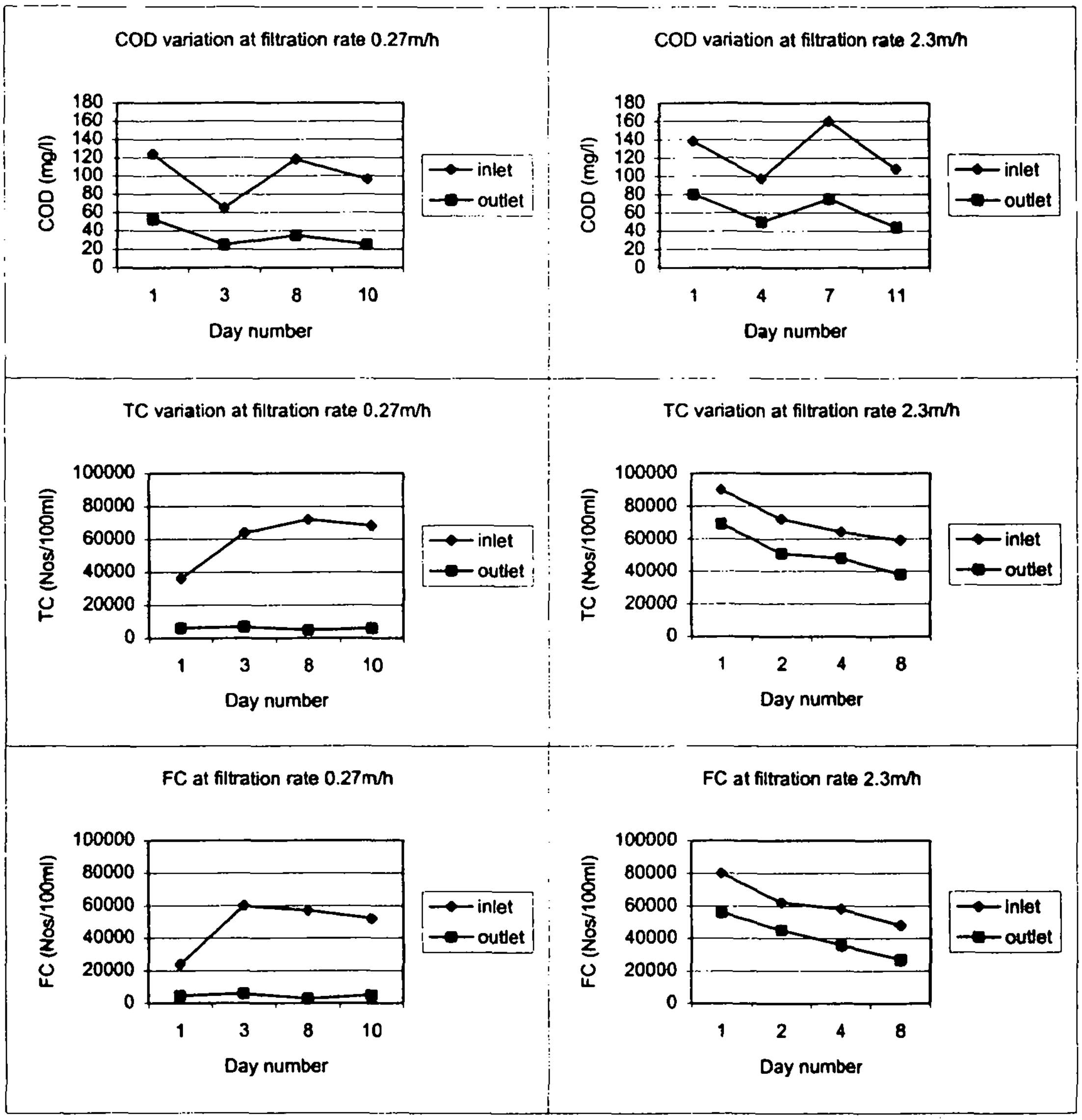

Fig. 5. Time variation of wastewater quality for the inlet and outlet.

The time variation of wastewater quality for the inlet and outlet is presented in Figs 3–5. Table 2 gives the average removal efficiencies of the constructed wetland.

Table 2. Average removal efficiencies of the constructed wetland

Indicator	Mean removal/reduction efficiency (%)	
	Phase 1	Phase 2
Turbidity	58	38
Apparent Colour	54	37
Suspended Solids	80	50
Dissolved Oxygen	74 (reduction)	54 (reduction)
Chemical Oxygen Demand	66	50
Total Coliform	90	28
Faecal Coliform	91	34

DISCUSSION

Temperature

For the two phases of the constructed wetland (P1 and P2), the wastewater temperature seemed to be more or less constant (no significant variation) for their inlet and outlet (Table 1 and Fig. 3). There were lower temperatures at the outlet, i.e. ranging from 22.1–27.9°C as compared to the inlet which ranges from 22.8–28.6°C for the case of phase P1. Because of the sub-surface flow, the heat radiation from the sun is limited and gives rise to lowering of influent wastewater temperature. Relatively high temperatures of the inlet and outlet were found for P1 as compared to P2 ranging from 24.2–28.2°C and 23.8–27.8°C respectively because at high filtration rate the retention time is less as compared to the low filtration rate and the plant shading is not effective to reduce the heat absorbed by wastewater.

Turbidity and colour

From Table 1 and Fig. 3, there is colour removal in the constructed wetland. The apparent colour of the influent ranged from 362 PtCo units to 556 PtCo units. The observed reduction in colour was from 28% to 61%. However, relatively high values of colour (>200 PtCo units) were observed at the outlet. This is probably due to decay of some plant material (Maltby, 1986; Sawyer and McCarty, 1978).

Reduction in turbidity at a filtration rate of 0.27 m/h ranged from 49% to 67% while at 2.3 m/h, it ranged from 37% to 45%. All phases had lower turbidity values at the outlet, probably due to the settling enhanced in the root zone of *Typha latifolia* reeds and the wind effect was smaller. High Turbidity values (>98 FTU) in the inlet is a result of the setback of WSPs. Figure 2 and Table 1 shows more or less constant average turbidity values for the inlet.

Conductivity and Total Dissolved Solids

The constructed wetland exhibit higher outlet values for the conductivity and TDS as compared to the inlet values (Table 1 and Fig. 3). The conductivity at the inlet ranged from 323 μs/cm to 474 μs/cm and that of the filtrate ranged from 335 μs/cm to 533 μs/cm. The TDS value ranged from 130 mg/l to 190 mg/l at the inlet and 150 mg/l to 210 mg/l at the outlet. This may be due to the release of nutrients back into the water as a result of plant decay, increasing the dissolved ions content and hence the conductivity. A rapid estimation of the TDS content of water can be obtained by electrical conductivity measurements (Sawyer and McCarty, 1978). The low inlet values for the conductivity (<600 μs/cm) reflects pre-treated wastewater by WSPs.

Suspended Solids

The suspended solids removal efficiency ranged from 67% to 87% at a low filtration rate and from 45% to 56% at a high filtration rate. The mean removal rate of suspended solids over the period of sampling was 80% and 50% achieved at low filtration and high filtration rates respectively (Table 2 and Fig. 4). Decrease of SS at low filtration rate was probably due to sedimentation and filtration in the reed bed within the wetland as the system matured.

pH value

The pH values of the influent ranged between 8.55–9.88 and for the filtrate ranged between 7.54–9.6. The mean value was 8.73 and 7.81 at a low filtration rate for the inlet and outlet respectively (Table 1). The corresponding figures at a high filtration rate were 9.54 and 9.15 (Table 1). This is not expected for influent from WSP as in this shallow pond with algal blooms, the pH must be around 10. During the sunlight hours of the day, the algae remove CO_2 from the water for use in photosynthesis and release O_2, this increases the pH to between 10–11 as the carbonate–bicarbonate equilibrium is destabilised. This process is reversed during the dark hours of the day, resulting in diurnal pH and dissolved oxygen variations (Sawyer and McCarty, 1978). The observed lowering of pH was probably attributed to the dilution from rainfall since the study was done during the rainy season (April–May).

Dissolved Oxygen

The influent appeared to have high DO as compared to the effluent from the constructed wetland because it is expected in shallow ponds with algal blooms like WSP, that during the sunlight hours of the day, the algae remove CO_2 from the water for use in photosynthesis and release O_2 and the carbonate-bicarbonate equilibrium is destabilised. During the dark hours of the day, the process reversed resulting in diurnal dissolved oxygen variations (Sawyer and McCarty, 1978).

DO at the inlet varied between 2.4–7.5 mg/l and for the filtrate varied between 0.6–2.2 mg/l. A drop in value of DO observed at a lower filtration rate was between 65 and 86% with an average value of 74% and between 41–67% with an average value of 53% at a higher filtration rate (Table 2 and Fig. 4). These drops in DO concentration could be attributed to biological activity in the reed bed filter including DO as a source of energy for root respiration and subsequently growing. The highest percentage reduction occurred at a lower filtration rate indicating that there was much intense biological activity taking place.

Chemical Oxygen Demand

The inlet COD concentration ranged between 65–160 mg/l while that of the outlet ranged between 25–80 mg/l with mean values as in Table 1. It was observed that at a lower filtration rate, there is a higher percentage reduction in COD value as compared to high filtration rate. Though the reed bed filter could not completely remove the organic load, it is evident that if reeds are allowed to grow properly and with a lower filtration rate, a high reduction in the organic loading can be obtained. With a filtration rate of 0.27 m/h, 57–74% reduction in COD was obtained and 42–59% COD reduction for a filtration rate 2.3 m/h was obtained (Table 2).

Total and Faecal Coliform

The study showed a reduction in total and Faecal Coliform considerably at the low filtration rate in phase 1 (Fig. 5). The Total Coliform removal efficiency at a low filtration rate ranged from 83% to

93% and from 25% to 36% at a high filtration rate. A mean reduction of 90% in total coliform was attained at a lower filtration rate and 28% reduction at a higher filtration rate (Table 2 and Fig. 3). For Faecal Coliform, the removal efficiency ranged from 81% to 95% at a low filtration rate and from 27% to 44% at a high filtration rate. Faecal Coliform mean reduction was 91% at a low filtration rate and 34% reduction at a high filtration rate (Table 2). Due to high microbiological activity at a lower filtration rate, probably a high reduction in coliform group was achieved. Other attributes for the coliform removal are probably sedimentation and filtration, natural die-off, ultraviolet radiation and excretion of antibiotics from roots of *Typha latifolia*.

CONCLUSION AND RECOMMENDATIONS

It is concluded that the constructed wetland can be used to upgrade the quality of WSP effluent to an acceptable level. From a bacteriological point of view, the constructed wetland could not completely remove the coliforms from the influent. The same could be said about the chemical quality. The low filtration rate provides high improvement in the quality of the WSP effluent and therefore design should be based on low filtration rates. Despite the small retention time, the system seems to work efficiently probably due to the high temperature of Dar es Salaam. It is therefore expected that, if the system is properly designed, maintained and operated with long retention time, it will result in high quality effluent for water reuse such as that for irrigation.

If the reeds are allowed to grow and thrive properly so that the roots can penetrate deep into the rock material, an increase in efficiency may be expected. Since the field investigations were carried out for a short period (4 weeks), the long term behaviour of the reed bed filter must be investigated.

Also since this was a preliminary study, a detailed study is needed to investigate the criteria for proposed design of constructed wetlands, the potential of other designs (horizontal surface flow, vertical flow, multistage treatment, etc.) and choice of aquatic plants to treat domestic and industrial wastewater in Tanzania.

Based on this study and other researches done worldwide, Tanzanians and Tanzanian investors are requested to adopt the wetland method of handling wastewater to complement or replace the existing wastewater treatment methods, as the benefits of wetlands for treatment of wastewater are (Loveridge *et al*., 1995; Smith, 1989):

1. For a developing country like Tanzania with limited technological advancement, natural treatment is achieved by constructed wetlands which have a zero energy requirement.
2. Reed bed treatments require relatively simple O&M costs which local people can be easily trained to do.
3. Constructed wetlands provide the reuse of both effluent and sludge. Treated effluent conforming to either Tanzania or WHO guidelines is suitable for irrigation. Sludge can be used as fertilizer for agriculture.
4. Seasonal variations in flow can be accommodated, as reed growth and bacteria activity are normally in phase with the temperature fluctuations.
5. Reeds can also be harvested to produce biogas, compost, raw material for basket wearing and roofing essentials.
6. Wetlands are also potential for groundwater recharge. Therefore, the return of cleaned water to the eco-system close to where it is used increases aquifer recharge and river flow, and allows for more natural cleansing through the river system.

In the view of the above benefits and since most of the domestic and industrial water use in Tanzania is located distant from one another and not connected to a main sewer and the space is available, then the alternative method such as wetland can be used for treatment of domestic and industrial effluents. Being a cost effective alternative for domestic and industrial wastewater treatment, the use of constructed wetland singly or in combination with other treatment systems is highly commendable.

REFERENCES

Abdulhussein B. S. (1997) Treatment of wastewater by method of constructed reed bed. Fourth Year Project Report, Department of Civil Engineering, University of Dar es Salaam (Unpublished).

APHA/AWWA/WPCF (1992) *Standard Methods for the Examination of Water and Wastewater*, 18th ed. American Public Health Association, USA.

Bakobi B. L. M. (1993) Conservation of wetlands of Tanzania. Wetlands of Tanzania. In *Proceedings of a Seminar on Wetlands of Tanzania*. IUCN.

Boon A. G. (1986) Visit by members and staff of WRC to Germany (GFR) to investigate the root zone method for treatment of wastewaters. WRc Report No. 376-5/1 WRc Processes, Stevanage, UK.

Finlayson M. and Moses M. (1991) *Wetlands International Waterfowl and Wetlands Research Bureau*, Slimbridge, UK.

Loveridge R., Butler J., Dewedar A. and Awad A. (1995) The growth and yield of crops grown hydroponically using treated sewage effluents. In *Research Monographs in Wastewater Treatment and Reuse in Developing Countries*. University of Portsmouth, UK, pp. 1–3.

Makerere University Kampala and Department of Civil Engineering (1997) Constructed Wetlands in East Africa, the Uganda chapter. Phase one report, Austria-East Africa Research Cooperation. pp. 4–25.

Maltby E. (1986) *Waterlogged Wealth: Why Waste the World's Wet Places*. Earthscan. Russel Press, Nottingham.

Mulungu D. M. M. and Mashauri D. A. (1997) A Survey report on wastewater treatment methods in Tanzania. Water Resources Engineering Programme, University of Dar Es Salaam, Tanzania (Unpublished).

Sawyer C. N. and McCarty P. L. (1978) *Chemistry for Environmental Engineering*, 3rd ed. McGraw-Hill Inc, USA.

Smith A. J. (1989) Wastewater: a perspective. In *Constructed Wetlands for Wastewater Treatment: Municipal, Industrial, Agricultural*, ed. D. A. Hammer, pp. 3–4. Lewis Publishers, Chelsia Michigan, USA.

Venus G. C. (1987) *Wetland Wastewater Treatment: A Review*. Whangarei, New Zealand.