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EFFECTIVE SIZING OF NATURAL SYSTEMS FOR GREY WATER TREATMENT USING LOCALLY DERIVED PARAMETERS

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Abstract: When properly managed, grey water can be a valuable resource, which agricultural and horticultural growers as well as home gardeners can benefit from providing an excellent nutrient sources for vegetation. Natural treatment systems such as constructed wetlands emphasizing on sustainability and wastewater reuse typically for agricultural irrigation/home gardening can be considered as an ideal alternative to close the loop in terms of nutrient capture and water conservation. This paper presents a part of an analysis done to estimate the locally derived treatment wetland parameters based on BOD5 removal mechanisms of a pilot scale subsurface horizontal flow constructed wetland (SSHF CW) treating greywater. A pilot scale SSHF CW with a surface area of 8.64 m2 and a substrate depth (with 20 mm aggregates) of 0.7 m was monitored. This is a part of a long term study carried out to test the viability of SSHFCW for treating grey water for agricultural reuse. The wastewater flow measurements were taken from the inlet and the outlet of the constructed wetland while monitoring the hydraulic (HRT) and organic loading rates. Water samples from four sampling points were collected on long term basis. Equations based on a kinetic model of a first-order piston flow reactor was used to calculate the relationship among the deign parameters appropriate for local conditions. The HRT varied from 3.3 to 4.7 d for maximum and minimum inflow loading rates observed. Using the data from the current study, a resizing exercise for a subsurface horizontal flow constructed wetland was carried out. Accordingly, a household with four people, discharging 720 L/d greywater with an average influent BOD5 of 300 mg/L could be treated up a BOD5 concentration of 25 mg/L using an area of 3.60 m2 of SSHF CW, implying only 0.975 m2 of percapita land usage.

Keywords: Hydraulic retention time; Inflow rate; Percapita land usage; Subsurface horizontal flow; Treatment efficiency

1. Introduction

According to the Sri Lanka Standard code of practise for the design and construction of septic tanks and associated effluent disposal systems SLS 745-Part 2, generally black water comprises of only 25% of combined (all) waste water. However, this small portion of black water contains 90% of Nitrogen, 60% of COD and 50 % of P. On the other hand, 75% of all wastewater contains relatively a small amount of pollutants. Furthermore, the nitrogen found in grey water can be filtered out and used by plants readily. However, grey water, if left untreated for a few days, will behave like sewage, becoming malodorous becoming anaerobic. Also, grey water decomposes much faster than black water.

When properly managed, grey water can be a valuable resource, which agricultural and horticultural growers as well as home gardeners can benefit from providing an excellent nutrient sources for vegetation.

Grey water irrigation has long been practiced in areas where water is in short supply. The engineering of these systems is still a relatively young technology; but it is one making rapid progress. As these systems utilize the nutrient (potential pollutant) content in the effluent, they constitute a real solution to the treatment /management of grey water.

A largely undocumented practice which occurs in the country (Sri Lanka) in most semi-urban and rural areas is the separation of black water from grey water. Usually the toilet waste goes to a septic system while all grey water is discharged mostly untreated directly into the environment, especially in rural areas or soakage pits in urban and semi urban areas. This pre-existing culture of source separation has the potential for the development of sustainable wastewater treatment systems based on the principles of natural treatment or ecological sanitation. Natural treatment systems such as constructed wetlands emphasizing on sustainability and wastewater reuse typically for agricultural irrigation/home gardening can be considered as an ideal alternative to close the loop in terms of nutrient capture and water conservation.

The demand for treated water is reaching to a level which might not be satisfied with the available resources even in places where there is no physical lack of it. In such situations, the necessity of effective and efficient wastewater treatment and promotion of water reuse would be highly productive. Hence, the use of highly favoured treatment systems such as constructed wetlands which are associated with natural removal mechanisms of pollutant removal could be successful applications especially in developing countries since, these systems combine low-cost, low-maintenance, simple and reliable operation, and high removal efficiency (Economopoulou and Tsihrintzis, 2003).

In general, Subsurface Flow (SF) constructed wetlands can treat a variety of wastewaters including domestic (black water and greywater) and municipal wastewater, industrial wastewater, agricultural and urban storm water runoff, combined sewer overflow and landfill leachate. Amongst most popular types of constructed wetlands, the Subsurface Horizontal Flow Constructed Wetlands (SHFCW) are considerably efficient in the removal of pollutants and eliminate some of the common problems such as bad odour, growth of mosquitoes, etc. Relatively, less research has been done so far on the use of constructed wetlands for greywater treatment in tropical areas and the design parameters still remain as black boxes due to the complexity of treatment mechanisms (Economopoulou and Tsihrintzis, 2003). In Sri Lanka too, constructed wetlands have not yet been identified as a very efficient and cost effective wastewater treatment method especially due to the notion of the high land demand, which is prohibitive is in urban and peri-urban areas. The main reason for this fact could be the insufficient research work on constructed wetlands specifically under the local environmental conditions of the country. The design information available in the temperate region of the world cannot be translated to Sri Lanka for optimization of pollutant removal mechanisms and design criterion of constructed wetlands due to the varying climatic conditions. Therefore, it is an essential requirement to estimate both design and operational parameters of the constructed wetland under the specific climatic and environmental conditions in the country.

Few research have been carried out focussing on parameter estimation and optimization of SF constructed wetland systems in Europe and United States. Economopoulou and Tsihrintzis (2003) have presented a simple criterion including the guidelines and mathematical models for the preliminary sizing of subsurface horizontal flow constructed wetland systems by considering the conditions of definite seasonal variations. But, this research work still has some limitations to apply the methodology in a tropical climate with the values given for certain parameters. However, the methodology could provide relevant guidelines for the estimation of parameters in a tropical climate and determining removal efficiencies of existing systems.

Wynn and Liehr (2001) developed a mechanistic compartmental simulation to model and predict seasonal trends in the removal efficiencies of HFCWs. The model consists of six sub-models representing the carbon cycle, the nitrogen cycle, an oxygen balance, autotrophic and heterotrophic bacteria growth, and a water budget. Therefore, this could make a close relationship with the project being concerned.

Vymazal (2005) has provided a very important discussion on subsurface horizontal flow and hybrid constructed wetlands including the pollutant removal mechanisms and their efficiencies with experimental results. Since the experimental data and analyses are based on the temperate continental climate conditions, it would not be possible to make a direct relationship with the local conditions.

Werner and Kadlec (2000) and Chzarenec et al. (2003) modelled wetland residence time distributions in temperate climes. Garcia et al. (2004) and Maloszewski et al. (2006) used tracer experiments to determine hydraulic parameters with different filter materials.

In Sri Lanka, the acceptance of, constructed wetlands as an efficient and cost effective wastewater treatment method is not yet established. This may be especially due to the scarcity of the land due to high population density as well as the insufficient research work on constructed wetlands, specifically under the local conditions. Therefore, it is an essential requirement to estimate both design and operational parameters of the constructed wetland under the specific climatic and environmental conditions in the country (Vymazal, 2011).

Treatment systems based on natural degradation processes, such as stabilization ponds and constructed wetlands, are particularly suited for domestic wastewater treatment and they require little or no energy, are relatively simple to operate, and show reliable treatment performance.

This paper presents a part of an analysis done to estimate the locally derived treatment wetland parameters based on BOD5 removal mechanisms of a pilot scale subsurface horizontal flow constructed wetland (SSHF CW) treating greywater. This is a part of a long term study carried out to test the viability of SSHFCW for treating grey water.

2. Methodology

2.1 Pilot scale subsurface flow constructed wetland

The subsurface flow constructed wetland system consisted of two settling tanks with a grease trap for the pre-treatment.

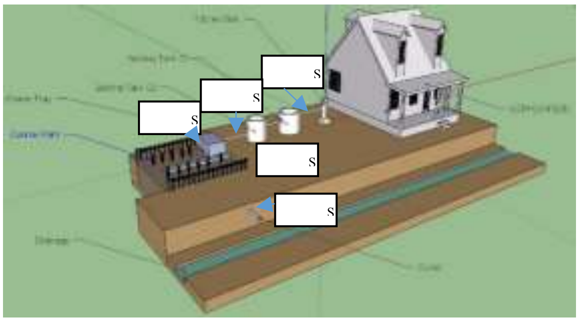

Figure 1. Configuration of pilot scale subsurface flow constructed wetland (SSFCW) indicating the sampling points (SP 1-4).

The pre-treated water was introduced into the wetland cell through a 50 mm perforated pipe and both inlet and outlet partitions were filled with 40 mm aggregates. The water passes through a 20 mm aggregate bed with baffles inside the wetland cell. Wetland cell was partitioned with wise to extend the flow path creating a long and narrow treatment cell. Wetland cell maintained a bed slope of 1% with the cannas as the vegetation.

Table 1 shows the characteristics of the pilot scale subsurface flow constructed wetland (fed with grey water discharged from a canteen) used for the study.

Table 1. Characteristics of the pilot scale subsurface flow constructed wetland

Parameter	value
Φ - porosity	0.435
d – substrate depth	0.70 m
L - length	4.00 m
W - width	2.16 m
V_e - effective volume	2.643 m^3
A - surface area	8.64 m^2

2.2 Flow measurement, sample collection and analysis

The wastewater flow measurements were taken from the inlet and the outlet of the constructed wetland while monitoring the loading rate. Water samples from four sampling points (at the sink outlet, after primary settling, at inlet to the CW and outlet of the CW) were collected on 1-2 week time intervals and analyzed for pH, Temperature, Turbidity, Conductivity, Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Nitrate Nitrogen, Nitrite Nitrogen, Total Phosphorous, Total Coliforms and Suspended Solids. However the present analysis concentrates mostly on the BOD_5 measurement data.

The efficiency of the concentration abatement of the pollutants were calculated using equation 1.

$$\text{Percentage abatement (\%)} = (Co - Ce)/Co \quad \text{Eq. 1}$$

Similar to Andreo-Martínez et al., (2016), equations derived by Reed et al. (1995) based on a kinetic model of a first-order piston flow reactor proposed was used to calculate the relationship among the deign parameters appropriate for local conditions (Eq. 2). By using equation 2 the theoretical wetland surface areas were calculated for the measured data.

$A_s = [Q(\ln C_0 - \ln C_e)]/K_t.d.n$ Eq. 2

Where, As-Surface wetland area (m^2), Co-inlet BOD_5 concentration, Ce- Outlet BOD_5 concentration, Q-inflow rate (m^3/d), K_t temperature dependent reaction coefficient (as given in eq. 3), d- treatment wetland depth in m, n- porosity of the substrate media.

$K_t = (1.104) . (1.06)^{(T_0-20)}$ Eq. 3

Where, K_t rate constant corresponding water temperature in wetland (d^{-1}), T_o is the water temperature in the treatment wetland, which was taken as 25 ^oC.

Hydraulic retention time HRT) for corresponding observed data was calculated by using equation 4.

HRT = (As .d.n)/Q Eq. 4

Previous studies (Andreo-Martínez et al., 2016, Karunaratne et al., 2011, Udukumburage et al., 2013) have shown that, BOD_5 can be considered as the governing parameter for the surface area optimisation of SSHF CW design when treated for reuse in irrigation as P and N removal is not an objective. P and N could be retained as plant nutrient.

Accordingly, using the observed BOD_5 data, relationships between the optimum wetland surface area, inflow rates and hydraulic retention time was calculated using equation 2 and trend lines were established using power functions to make predictions.

3. Results and Discussion

The ratio of BOD5/COD is related to the biodegradability of the organic matter present in the water. In the present study, the ratio BOD5/COD for influent wastewaters had an average of

0.74 ± 0.08 in raw wastewater, a characteristic value for wastewater of high biodegradability. The average BOD5 of the influent was 892 ± 18 mg/L, a relatively higher value than the usual domestic grey water in Sri Lanka. This higher value is mainly due to the food varieties, mostly Sri Lankan style menus serving in the staff canteen. Average PO43-, NO3-and BOD of the influent greywater over the study period was 1.79, 42.62 and 892.19 mg/L respectively.

Figure 2 shows the variation of treatment efficiencies with varying loading rates. Inflow rate ranged from 0.56 m3/day to 1.55 m3/day.

At all loading rates, treatment efficiencies of BOD5 did not fall below 65%. At the minimum loading rate all parameters measured displayed efficiencies ranging from 62 – 88%, removal of P showing the minimum while BOD5 showing the highest. Same trend was observed generally at all loading rates. Even at highest loading rate of 1.55 m3/d, N removal efficiency of more than 50% was recorded.

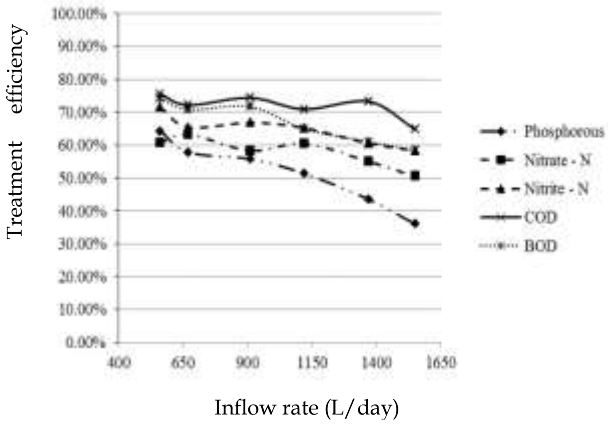

Figure 2. Variation of treatment efficiency of pollutants with varying inflow rate of the subsurface horizontal flow constructed wetland

The optimum retention time that would yield the minimum required treatment level was calculated using the measured data and the temperature dependent reaction rate constant for BOD5 was calculated based on the equations 2 and 3. The HRT varied from 3.3 to 4.7 d for maximum and minimum inflow loading rates observed. This is comparatively lesser than the HRT reported from temperate region but reasonable when considering the higher temperature observed in Sri Lanka (Andreo-Martínez et al., 2016).

Generally, sizing of wetlands treating greywater is performed based on the COD or BOD5 removal efficiencies. Targeting higher removal efficiencies of N and P through constructed wetlands demands higher land requirements hence making such targets impractical. It was observed that very few models have been developed to simulate pollutant removal processes in SFCWs and only a fewer number of models of these are applicable for SSHFCWs (Langergraber, 2008). In fact, many of those models are applicable for a particular climate or a clime where the model has been developed. Such models should be modified before applying for different conditions. Modification of an existing model can be rather difficult and complex than developing a new model in relation with the local conditions. Modelling of pollutant removal mechanisms of a SSHFCW in a particular climate and sizing of the wetland systems would be a challenge because, the procedure should be consisted of the formulation of removal processes, the estimation of parameters in the model and the sizing of the system.

It is known that efficiency of wastewater treatment depends on the influent water quality, climate conditions as well as substrate type and plants used (Aleksandra et al, 2008). The reaction rate constants yielded in this study were calculated under high loading rates (i. e. three times the original designed). Therefore, influent water quality had a higher variability over the prolonged study period. Hence it was important to calculate the reaction rate constants under varied loading rates and compare the same for better accuracy. Kt was calculated at 25 oC was 1.5 d-1.

Figure 3 shows the relationship between the inflow BOD loading (in g) of greywater and the load reduction per unit surface area (kg m2).

Figure 4 shows the relationship between the wetland surface area and the hydraulic retention time calculated for the SSHF CW in consideration. Equations 2 and 3 were used to calculate the HRT and wetland surface areas based on the observed data. As mentioned earlier, the estimations of hydraulic retention time for specific treatment levels was based on the BOD5 treatment efficiency only. Figures 3 and 4 can be used with reasonable accuracy to size treatment wetland cells to treat greywater discharged from households. The relevant estimation of flowrates can be based on SLS 745 (Part 2) standards.

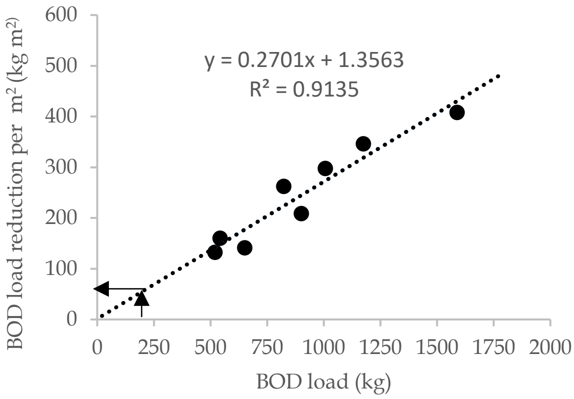

Figure 3. The relationship between the inflow BOD loading (in kgs) of wastewater and the load reduction per unit surface area (kg m^2).

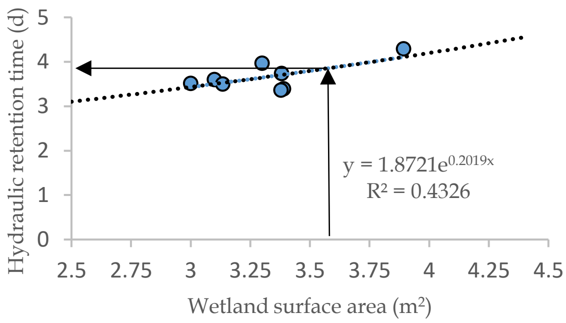

Figure 4. Relation between the wetland surface area (A_s) and the HRT.

Using the outcomes from the current study, a resizing exercise of SSHFCW was carried out as shown below;

A household with 4 people was considered. As per the SLS standards 745 (part 2), greywater discharge of 180 L/p/d accounts for 720 L/d of grey water from the household. An average influent BOD5 of 300 mg/L (according to literature it can vary from 200-500) and effluent concentration of 25 mg/L was considered. Hence, BOD load will be 216 g/d (720*300/1000). A more stringent discharge standard was considered due to the undiluted discharge conditions prevailing at domestic environments for irrigation purposes.

Using Figure 3, BOD5 load reduction per m2 corresponding to 216 g of BOD5 load can be estimated to be 59.68 BOD/m2. As such the surface area required is 3.6 m2 (216/59.68). Using figure 4, HRT corresponding to 3.6 m2 of wetland surface area is estimated as 3.9 days. According to the present calculation, average strength grey water, usually discharged from a typical Sri Lanka household can be treated using an area of 0.975 m2/person surface area of a SSHF CW.

If a ratio L/W of 3:1 is assumed (Andreo-Martínez et al., 2016), L and W can be calculated as, W=1.10 m while L= 3.30 m, respectively. The plan dimensions can even be readjusted to maintain the total surface area depending on the space availability of the location. The depth of the substrate is 0.7 m. This can be considered as a size which can be conveniently accommodated even in an urban setup and mimic a flower trough if plants such as Cannas are used.

4.0 Conclusion

An analysis was done to estimate the locally derived treatment wetland parameters based on BOD5 removal mechanisms of a pilot scale subsurface horizontal flow constructed wetland (SSHF CW) treating greywater. The treatment wetland resizing exercise for a subsurface horizontal flow constructed wetland revealed that for a household with 4 people discharging 720 L/d greywater with an average influent BOD5 of 300 mg/L could be treated up a BOD5 concentration of 25 mg/L using an area of 3.6 m2, implying only 0.975 m2 of percapita land usage.

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