PILOT SCALE STUDY: USE OF SUBSURFACE FLOW CONSTRUCTED WETLANDS FOR DOMESTIC WASTEWATER TREATMENT IN SRI LANKA

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Abstract

There is no any environmentally acceptable standard method practiced to treat domestic grey water in Sri Lanka. Many methods of wastewater treatment have been researched and employed by responsible nations around the globe. An alternative approach in addressing this crisis is the adoption of low cost sanitation facilities, such as an engineered reed bed treatment system. A reed bed typically consists of a substrate confined within an impermeable containment supporting macrophytes such as reeds or rushes. Treatment occurs within the bed as a result of a number of interrelated physical, chemical and biological processes that occur during the water's passage through the bed.

This treatment technology is already being applying in Europe, Australia and North America where temperature greatly fluctuates during summer and winter seasons. But for being a tropical country with relatively high ambient temperature throughout the year, it is not economical to directly apply the designs developed for those countries as they require relatively high retention time. Major objectives of this research were to find out the optimum retention time needed for the sub-surface horizontal flow constructed wetlands, removal efficiencies of major pollutants present in the domestic grey water and comparison of three types of commonly available reed varieties (Common reed, narrow leaf cattail and bulrush) found in Sri Lanka for the removal efficiencies and their tolerance/ propagation in the artificial wetland conditions.

Out of three reed varieties, highest propagation was observed in Common Reed while lowest was observed in Bulrush. It was observed that 2.6 days retention time is sufficient to treat the wastewater up to the limits prescribed by the National Standards for discharging effluent into inland surface waters. The treated effluent was clear, colourless and odourless and 93-97% COD, 87-90% BOD, 99% TSS reductions were observed in the tested beds while in Coliforms and E.coli analyses, reductions were within 83-97% and 91-99% respectively.

Key words: reed bed, grey water, treatment

1. Background

Water is one of the most important elements involved in the creation and development of healthy life. This is the reason why humans have to take special care of this extremely valuable element. One of the commonly found environmental problems in developing countries is water pollution caused by direct disposal of untreated wastewater. Discharging untreated effluent into watercourses or land may cause environmental degradation and serious public health risks with the increased population density.

In Sri Lanka, at domestic scale, there is no any environmentally acceptable method used to treat and dispose wastewater generated from the individual houses. On site septic tank and soakage pit is only available technology to treat black water. Rest of the wastewater known as grey water i.e. kitchen, laundry, bathroom are discharged directly on to the land or nearby water ways.

Many methods of domestic level wastewater treatment have been researched and employed by responsible nations around the globe (Geary P M, 1998; Yocum D.,2006). An alternative approach in addressing this crisis is the adoption of low cost sanitation facilities, such as an engineered reed bed treatment system. Use of reed beds for wastewater treatment is appropriate in smaller communities and individual houses because they are easily constructed, inexpensive to maintain and very efficient. However, the major disadvantage is the relatively high land area compared with other high tech treatment options.

During the literature survey, it was revealed that various studies have been carried out to see the potential of constructed wetlands for treatment of municipal and industrial effluent (Abira M. A.,2006; Reed S. C,1993; Yocum D.,2006) as well as for sewage (Koottatep *et al*,2001). But most of these studies have been done in Europe, Australia and North America where temperature is greatly fluctuates during summer and winter seasons. Therefore those data specially retention times may not be directly applicable here as Sri Lanka is a tropical country where there is no considerable temperature fluctuations throughout the year.

Constructed wetlands (CW) are man-made systems aiming at simulating the treatment processes in natural wetlands. A reed bed typically consists of a substrate (usually gravel) confined within an impermeable containment supporting macrophytes such as reeds or rushes (Figure 1). Water enters via an inlet structure and flows horizontally over a certain period of days to the outlet structure. Treatment occurs within the bed as a result of a number of interrelated physical, chemical and biological processes that occur during the water's passage through the bed.

These mechanisms include:

- Settling of suspended particulate matter.
- Filtration and chemical precipitation through contact of the water with the substrate and litter.
- Chemical transformation.

- Adsorption and ion exchange on the surfaces of plants, substrate, sediment, and litter.
- Breakdown and transformation of pollutants by microorganisms and plants.
- Uptake and transformation of nutrients by microorganisms and plants.

The basic mechanism of organic matter degradation in constructed wetlands is plant bacterial symbiotic reactions, in which gaseous oxygen photosynthetically produced or taken up for respiration by the plant is used by aerobic and facultative bacteria (Polprasert et al., 1998).
- Predation and natural die-off of pathogens.

1.1 Advantages of Constructed Wetlands

Constructed wetlands are a cost-effective and technically feasible approach to treating wastewater and runoff for several reasons:
-Wetlands can be less expensive to build than other treatment options.
-Operation and maintenance expenses (energy and supplies) are low.
-Operation and maintenance require only periodic, rather than continuous, on-site labour.
-Wetlands are able to tolerate fluctuations in inflow.
- They facilitate water reuse and recycling.

In addition:
- Provide habitat for many wetland organisms
- Can be built to fit harmoniously into the landscape
- Provide numerous benefits in addition to water quality improvement, such as wildlife habitat and the aesthetic enhancement of open spaces
- An environmentally-sensitive approach that is viewed with favour by the general public.

1.2 Limitations of constructed wetlands

In spite of the various advantages, there are limitations associated with the use of constructed wetlands:
-They generally require larger land areas than do conventional wastewater treatment systems. Wetland treatment may be economical relative to other options only where land is available and affordable.
- Wetland treatment efficiencies may vary seasonally in response to changing environmental conditions, including rainfall and drought. While the average performance over the year may be acceptable, wetland treatment cannot be relied upon if effluent quality must meet stringent discharge standards at all times.
- The biological components are sensitive to toxic chemicals, such as ammonia and pesticides. Flushes of pollutants or surges in water flow may temporarily reduce treatment effectiveness.

1.3 Wetland Types

Depending on the water flow pattern, there are different types of constructed wetlands as vertical flow, horizontal surface flow and horizontal sub-surface flow. For this study, sub-surface horizontal flow wetland is selected as the grey water flows through the system beneath the rock surface, which eliminates the risk for standing pools for mosquito breeding and it is not aesthetically pleasant to have open treatment systems within the home garden.

1.4 Benefits, outputs and outcomes will have on the beneficiaries and end-users

1. After the treatment, the treated water can be either directly discharged to the environment or used for some domestic applications like gardening. This is very advantageous especially for the people in water limited areas as part of the used water can be recovered back.

2. This is a kind of back-to-nature approach and provides intangible benefits by increasing the aesthetics of the site and enhancing landscape. It acts as a small scale wetland and can be a habitat for water related wildlife. Can be built as a part of the home garden by changing the shape that follows the natural contours. Instead of reeds, flowering plants like cannas and some edible plants like spinach (*Basella alba*), Lasia (*Lasia spinosa*), Water spinach (*Ipomoea aquatica*) can be planted in the bed.

3. Sustainable system operation and maintenance

4. In addition to the initial construction cost, operation and maintenance of engineered reed beds are inherently simple and inexpensive.

2. Methodology

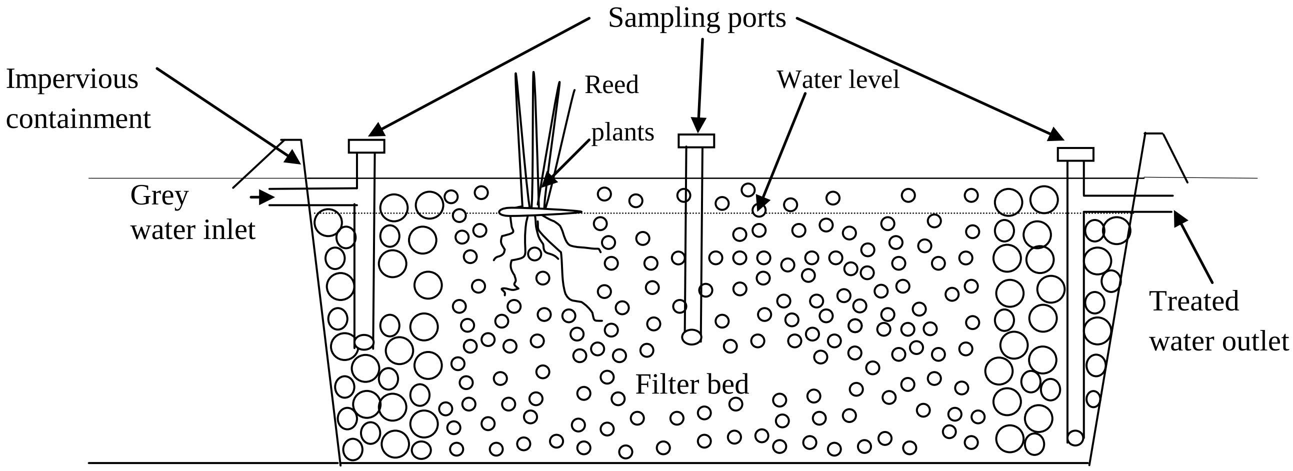

Figure 01: Cross section of subsurface flow system

Four identical tanks were constructed using precast concrete panels. Four inch diameter PVC pipes were used for inlets and outlets. Beds were filled with metal by keeping 0.4 porosity and each having 2.6 days hydraulic retention time (HRT). Bed no. 01 was kept as the control bed and other three beds were planted with three different types of wetland plants - Common Reed (Phragmites spp.), Bulrush (Scirpus grossus) and Narrow Leaf Cattail (Typha angustifolia) respectively. Total number of plants planted in each test bed was 30.

Expected influent properties were as follows. BOD^5_{20}-300 to 400 mg/l, COD-650 to 750 mg/l, TSS-80 to 160 mg/l, pH-6 to 7.5 mg/l. Expected quality of treated water is to comply to the existing tolerance limits for the discharge of industrial waste in to inland surface waters gazetted by Central Environmental Authority of Sri Lanka where BOD^5_{20}-30 mg/l, COD-250mg/l, TSS-50mg/l, pH-6 to 8.5 mg/l and Faecal Coliform, MPN/100ml,maximum 40.

2.1 Feeding water

Feeding water used was grey water from one of the departments of NERDC, which includes the effluents from bathrooms and the rest room sink where around 30 people use to wash their hands during lunch time. In addition to that, concentrated effluent collected from the Canteen which contained washed water of utensils, raw rice and vegetable was fed to the system daily. Mixing ratio of these two streams is 2 parts of bathroom water : one part of kitchen water. This ratio is selected by analysing domestic grey water generation rates from each activity in the country. The influent was initially filtered prior to enter into the reed bed through a fine stainless steel mesh fitted to the inlet of the grey water collection tank. Feeding of the effluent was started just after the completion of reed planting. Effluent was collected into a storage tank and sent to four beds arranged in parallel. Feeding time is from 8.30 am to 4.00 pm and feeding volume is 400 l/day/bed.

2.2 Parameters monitored

Wastewater characteristics (pH, BOD, COD, TSS, NH_3-N, faecal Coliform) were measured in the inlet, middle and outlet of each bed. Samples were taken for the analysis three months after the reed plantation. In addition to that temperature measurements were taken at following locations; ambient, on the bed surface, at the water level of each bed (4" below the surface) and one feet below the water level of each bed. Macrophyte density and growth was also taken in to consideration in order to find out their tolerance to artificial wetland condition.

2.3 Sampling, Collection and Analysis

2.3.1 Sampling points

Samples were collected during day time from the Inlet, middle and outlet of each bed. All the samples except for bacteriological analysis were collected in 500mL plastic bottles. Each sample bottle was pre rinsed with detergent solution and distilled water and rinsed once with sample wastewater before taking the samples. From the inlet and middle sampling points, samples were collected using a hand pump. Before collecting in to the bottles, water was pumped away for five minutes period. All water samples at outlets were collected manually. For bacteriological analysis, samples we collected to the sterile glass bottles and send to the external laboratory under refrigerated conditions. Analytical methods used to analyse wastewater samples were undertaken in accordance within APHA (2005). A brief description of the analytical procedures used during this study is outlined below.

Table 01 : Test methods, principles and calibration standards

Test	*Principle*	*Method and Calibration Standards*
pH	*Electrometry*	*APHA 4500-H+ B*
Total Suspended Solids (TSS), mg/l	*Filtration/Drying at 1050C*	*APHA 2540 D*
Biological Oxygen Demand (BOD5 20), mg/l	*Respirometry*	*APHA 5210 D*
Chemical Oxygen Demand (COD), mg/l	*Colorimetry*	*APHA 5220 D*
Ammonical Nitrogen (NH3-N), mg/l	*Colorimetry*	*Nessler method (USEPA accepted)*
Coliform/100 ml	*Fitration*	*SLS 614:1983 Part 2*
E.coli/100 ml	*Fitration*	*SLS 614:1983 Part 2*

3. Results

3.1 Macrophyte density and growth

Table 02 : Macrophyte density and growth

Plant type	*No. of plants in each bed after 11 months*	*Root length (cm)*	*Plant height (cm)*
Common reed	*315*	*58*	*250*
Narrow leaf Cattail	*294*	*46*	*231*
Bulrush (Thunhiriya)	*219*	*18*	*158*

Out of three reed varieties, highest propagation was observed in Common Reed while lowest was observed in Bulrush. In addition to the planted reeds, in the latter part of the research after completion of the sample testing, some other edible plant varieties such as spinach (*Basella alba*), bitter goad (*Momordica chorantia*) , Oriental Melon “Kekiri” (*Cucumis melo)* were grew well in the control bed.

3.2 Wastewater characteristics

3.2.1 Physical characteristics

Influent was turbid and light grey in colour. Effluents of all the four beds were very clear and colourless. There was no any odour in the effluent coming out from three beds planted with reeds. But some odour was noticed in the effluent samples taken from the control bed.

3.2.2 Chemical characteristics

Outlets of all beds showed more than 90% reduction in COD and all the values for outlet and middle sampling locations were far below the prescribed limits. Prescribed limit for BOD to discharge into inland surface water bodies is 30 mg/l. Results shows that BOD in the outlets of all the beds were within the limits. In mid point sampling locations, value of control bed exceeded the limit and the average value was 48 mg/l. When taken as average, initial TSS of 297 mg/l was reduced below 5 mg/l at the outlets of all the beds. When consider the pH, there was no any significant difference in the influent and effluent of all the beds and the values were within 6.5 to 7.5. Similar to pH, both initial and final ammonical nitrogen values were within the standard limits.

3.2.3 Coliform and *E. coli* counts

Both in Coliforms and *E.coli* analyses, it was observed that the highest reductions in bacterial counts in the treated wastewater samples were observed in the control bed. Coliform count of 4700 numbers in 100 ml of raw effluent has reduced to 160 in the outlet and the reduction was 97%. Same pattern was observed for E. coli and 3200 numbers/100 ml has reduced up to 24 numbers/100 ml after the treatment.

In order to find out whether there's any relationship between the Coliform / *E.coli* counts with the temperature, at each bed temperature measurements were taken at two depths using thermocouple wires and a data logger. One point was on the existing top water layer in each bed and the other location was one feet beneath the existing top water layer. It was observed that highest temperature values were recorded in the control bed without any plants where the highest Coliform reduction was also observed. But when compared with the other three beds, temperature difference was not very significant and is around 40^0C.

Table 03 : Chemical and microbiological characteristics of samples

Reed / Parameter	*Inlet*	*Control Bed*		*Common Reed*		*Bulrush*		*Cattail*	
	mg/l	*mg/l*	*% reduction*	*mg/l*	*% reduction*	*mg/l*	*% reduction*	*mg/l*	*% reduction*
Chemical Oxygen Demand (COD)	*355*	*14*	*96*	*9*	*97*	*21*	*94*	*9*	*96*
Biochemical Oxygen Demand (COD)	*193*	*20*	*90*	*20*	*90*	*26*	*87*	*24*	*88*
Total Suspended Solids (TSS)	*297*	*1*	*99.7*	*4*	*98.7*	*1*	*99.7*	*2*	*99.3*
E-coli/100 ml	*3200*	*24*	*99*	*120*	*96*	*300*	*91*	*44*	*99*
Coliforms/100 ml	*4700*	*160*	*97*	*500*	*89*	*450*	*90*	*800*	*83*

4. Discussion

Sizing of beds for a residence time of approximately 5 days has become standard practice in the Australian state of New South Wales (NSW) where reed beds (horizontal subsurface flow constructed wetlands) have been employed as secondary treatment devices in on-site and decentralized wastewater management systems for over a decade (Davison *et al*, 2005). As already mentioned in the background, these residence times are estimated on the data taken from the research and field studies done in Europe, Australia and North America where temperature is greatly fluctuates during summer and winter seasons. With this 5 days residence time, average BOD reduction was 83.8% (Davison et al, 2005). In this research, 2.6 days residence time was used for all four beds and achieved 88 to 90 % BOD reduction. Similar HRT of 3 days reported in a study conducted in Korea (Ahan *et al*, 2004) All the other tested parameters were also well below the standard limits with 2.6 HRT So being a tropical country where there is no considerable temperature fluctuation throughout the year, in Sri Lanka we can have relatively low residence time than those practiced in the temperate countries while achieving the higher pollution reduction efficiencies.

According to Davison *et al*, 2005, it is rare to achieve concentrations < 1,000 cfu/100mL of faecal coliforms after five days residence in a reed bed. But it was observed in all the tested four beds, Faecal coliform count is below 800 CFU/100 ml and as a percentage, lowest reduction of 83% was observed in the bed planted with Bulrush while the maximum reduction of 97% was observed in the control bed. The possible reason for this highest reduction in the control bed is direct exposure of the metal to the sun light and thereby getting heated up to higher temperatures as there is no plant coverage.

It can be concluded that all the tested beds including the control bed having no plants showed the pollution reduction up to the standard permissible levels. Only difference of effluent characteristics between reed planted beds over control bed was disappearance of odour from the treated water with the presence of plants. In addition to eliminating odour, the planted bed adds an aesthetic value to the home garden by utilization the space for flowering/ edible plants instead of reeds. Other advantage is that there is no need of addition of water and fertilizers to the plants as they can take their nutritional requirements from the wastewater medium where they grow.

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