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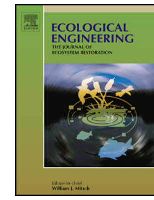

Performance evaluation of an Integrated On-site Greywater Treatment System in a tropical region

Y.M. Patil[a], G.R. Munavalli[b,*]

[a] Department of Civil Engineering, Rajarambapu Institute of Technology, Rajaramnagar, Islampur, 415414 District Sangli, M.S, India
[b] Department of Civil Engineering, Walchand College of Engineering, Sangli 416415, M.S, India

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ABSTRACT

Integrated On-site Greywater Treatment System (IOGTS) with primary (settling/filtration), secondary (constructed wetland) and tertiary (adsorption) treatment was used to treat greywater from hostel. A field scale IOGTS was constructed for hostel located in Sakharale, District Sangli (M.S.) India. The performance evaluation of IOGTS was carried out for a study period of one year. The quality parameters used to assess feasibility of disposal for land application were COD, TKN, suspended solids, and pathogens. The effect of hydraulic loading rate (HLR), Hydraulic Retention Time (HRT) and Organic Loading Rate (OLR) on performance of the system was also studied. A consistent performance (30% COD removal and 70% turbidity removal) was observed in upflow-downflow filter throughout the study. Secondary treatment in IOGTS was evaluated for HLR (10–100 mm/d) and OLR (10–350 kg COD/ha.d). HLR (40 mm/d) and OLR (170 kg COD/ha.d) showed a better removal efficiency of COD. Overall performance of IOGTS for COD, TKN and pathogen removal was observed to be 70%, 70% and 85% respectively. Therefore, IOGTS can be considered to be an appropriate treatment option to treat greywater to satisfy effluent standards for its reuse in land application.

1. Introduction

Excessive use of natural water resources due to rapid urbanization has necessitated search for alternative sources of water for non-potable purposes. The potential sources which can be explored include harvested rainwater, reclaimed water, and sea water. Reclaimed water from every household is an appropriate choice as it provides scope for water conservation, pollution prevention and decentralized treatment. Greywater and blackwater are two major contributory streams of domestic wastewater. Greywater has great potential for reuse due to its availability and low pollutant strength, when compared to sewage (Gajurel et al., 2003; Hernández Leal et al., 2007). In developing countries like India, reclamation of greywater for non-potable use is essential due to non-existence of sewerage system in most of the towns/cities and groundwater pollution due to disposal of untreated sewage.

Physical, chemical and biological systems can be used for greywater treatment. Physical treatment systems normally include filter to remove suspended solids. Chlorination and photo-catalytic oxidation are chemical treatment methods. Membrane Bio-Reactor (MBR), Moving Bed Bio-reactor (MBBR), Up-flow Anaerobic Sludge Blanket (UASB), Rotating Biological Contactor (RBC) and Constructed Wetland (CW) have been used as biological treatment options. Biological processes are considered to be the most appropriate for greywater treatment because of their efficient removal of organics (Jefferson et al., 2004; Pidou et al., 2007). The combination of biological system preceded by physical filtration is considered to be the most economical and feasible solution for greywater recycling (Lee et al., 2009). The mechanized treatment systems like MBR, UASB and RBC may be appropriate for centralized and larger capacity treatment systems. There is a need to induce sustainable concepts of wastewater treatment in decentralized greywater treatment. CW based biological treatment preceded by pre-treatment with filter and followed by tertiary treatment with adsorptive beds is an appropriate combination of complete greywater treatment.

CWs are engineered ecological treatment systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soil, and the associated microbial assemblages to assist in treating wastewater (Vymazal, 2010). Sub-Surface Flow (SSF) CW system is suitable option for the on-site treatment and reuse of greywater as it leads to lesser problems

* Corresponding author.
E-mail addresses: yashawantmpatil@rediffmail.com, yashawantmpatil@rediffmail.com (Y.M. Patil), guru.munavalli@walchandsangli.ac.in (G.R. Munavalli).

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arising from odor, vectors or public exposure than surface flow CWs (Yang et al., 2001). Studies showed that SSFCWs were effective in removing pollutants such as suspended solids, organic matter and nutrients from wastewater. The purification mechanisms involved are microbiological degradation, plant up-take, filtration, sedimentation and adsorption. Anaerobic and aerobic processes were reported to occur within pores of filter media (Yalcuk and Ugurlu, 2009). The performance data available on CW systems is for temperate climates, but the treatment performance is expected to be significantly higher in tropical areas because of the high temperature and associated higher microbial activity (Konnerup et al., 2009). The vegetation in CW plays a positive role in the removal of pollutants and most of the plants used are weeds characterized by the higher rate of growth. *Colo-casiaesculenta* (Bindu et al., 2008; Mbuligwe, 2004), *Typha latifolia* (Mbuligwe, 2004; Akratos and Tsihrintzis, 2007; Sonavane et al., 2007; Munavalli and Pise, 2012), and *Phragmites australis* (Lee et al., 2009) were previously adopted in Konnerup et al. (2009) studied performance of two ornamental plants *Canna indica* and *Heliconia* (Saumya et al., 2015) in a pilot-scale SSFCW for treating domestic wastewater. COD removal was reported to be better as compared to the removal of total nitrogen (TN) and Total Phosphorus (TP). It was further reported that plant uptake was a significant removal process for nutrients in lightly loaded systems. The other studies reported for treating greywater using CWs were (NEERI, 2007; Frazer-Williams et al., 2008; Langergraber et al., 2009).

It can be seen from literature review that there are very few studies reported on greywater treatment by CW in tropical climate. The potential of CW for treating greywater can be explored if a pre-treated/filtered feed is used. The use of ornamental plant in CW will add aesthetic value to integrated treatment system and derive intangible benefits in terms of long-term good operation and maintenance. Integrated On-site Greywater Treatment System (IOGTS), used in the present study, consists of pre-treatment, biological/secondary treatment with CW, and post-treatment with adsorption system. The performance evaluation of IOGTS has not been reported in the literature. The laboratory/small scale evaluation of IOGTS may not be an appropriate choice for performance evaluation. The small scale evaluations normally provide the results on higher side compared to evaluations for large/field scale treatment. In this context, the performance evaluation of aesthetically good looking IOGTS on field scale for longer period is required for contributing to existing knowledge on greywater treatment.

In this study, IOGTS was constructed for treating greywater from hostel and performance was evaluated for a year. The greywater treatment system consisted of settler, sand/gravel filter, CW, and coal filter. The performance evaluation study was conducted to assess the potential to remove organic matter and nutrients from greywater. The effects of Organic Loading Rate (OLR), Hydraulic Loading Rate (HLR) and Hydraulic Retention Time (HRT) were also assessed. To the knowledge of authors this is a first attempt on large scale IOGTS with long term monitoring in tropical climate.

2. Materials and methods

2.1. Source of greywater

Greywater generated from boys' hostel in the campus of Rajarambapu Institute of Technology (RIT), Sakharale (Maharashtra state in India) was used as a feed. The hostel accommodates 150 students and has 24 bathroom and water closet (WC). The wastewater from bathroom and WC was collected separately through two-pipe plumbing system. The blackwater was diverted to septic tank and greywater was used as a feed to IOGTS. The grab samples of raw greywater for characterization were collected from an inlet chamber just before greywater enters the treatment system. In order to ensure uniform quality of greywater the grab samples were collected at 10 am on each of the sampling days. Three samples were collected on each sampling day and the period of study is 345 d (260 d of actual run).

2.2. Integrated On-site Greywater Treatment System

A field scale IOGTS was designed and constructed for average flow rate of 4500 L/d. The constructed treatment facility for IOGTS has pre-treatment, secondary/biological CW treatment and tertiary treatment processes. Figs. 1 and 2 show the details of plan, section and photographic view of IOGTS respectively. It consists of three stage treatment viz. pre/primary [settling cum equalization tank, Up-Flow Down-flow Filter (UFDF)], biological (CW) and post/tertiary (vertical flow charcoal filter and water hyacinth). The provision of settling cum equalization tank enables settling of suspended solids and normalizes the quality greywater. The settling tank/equalization tank is 2.50 m long, 1.50 m wide and 1.0 m deep with 0.30 m freeboard. The average detention time provided was 20 h as no chemical was used to aid settling. The outlet, which was regulated by a flow control valve, was kept above the sludge zone to restrict the entry of suspended solids into the UFDF which further refines quality of greywater. A three compartment UFDF system with a sequential flow pattern of up-flow, down-flow and up-flow was designed as per the guidelines of NEERI (2007). The size of each compartment is 1.50 m long, 0.80 m wide and 0.70 m deep. The first compartment was filled with 20 mm uni-sized gravel. The gradation of an ideal filter (coarser to finer in the direction of flow) was maintained in second and third compartments. Graded gravel of size 8 mm–12.5 mm and graded sand of size 1 mm–4.75 mm were used in the second and third compartment respectively. SSF conditions were maintained in all the three compartments and the flow was uniformly distributed within filter area by three equally spaced ports in each compartment.

CW unit consisted of inlet structure, horizontal flow SSFCW system and outlet structure. The inlet and outlet structures were dimensioned with $2.50\,m \times 0.30\,m \times 1.00\,m$. The overall dimension of CW unit was $10\,m \times 2.50\,m \times 1.0\,m$. The unit was divided into three compartments by vertical baffles so as create channelized (horizontal) SSF conditions. It can be described as around the end vegetated bed baffled reactor. The total length of channelized/horizontal flow was 30 m with a width of 0.75 m. The channelized flow will also ensure maintenance of plug flow conditions within the CW system. *Canna indica* was planted in 0.60 m deep support gravel medium of size 6 mm–10 mm *Canna indica* was used because of its i) potential to remove contaminants; ii) aesthetic/ornamental value; iii) local availability; and iv) growth in tropical climate. The flow regulation valves were provided at both inlet and outlet structures.

The post-treatment system was provided with charcoal filter followed by water hyacinth system. The up-flow charcoal filter of size $1.5\,m \times 0.90\,m \times 0.90\,m$ was provided with 0.60 m deep and 10–25 mm effective size charcoal bed. Charcoal was thoroughly washed with clean water before it was placed in the filter. The treated greywater was collected in storage tank of size $1.50\,m \times 2.45\,m \times 1.20\,m$ and used for gardening. There were four sampling ports (S1, S2, S3 and S4 shown in Fig. 1) provided for the collection of samples during the period of study. The sampling locations were chosen in order to assess the quality of greywater after pre-treatment, secondary and tertiary treatment. Three samples were collected at every sampling location each time.

IOGTS was operated for greywater treatment after vegetation was fully established in CW system. Initially, *Canna indica* was planted in gravel bed of CW system and fed with freshwater continuously. The growth of vegetation was monitored for its height