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Removal of chemical and microbial contaminants from greywater using a novel constructed wetland: GROW

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ABSTRACT

The availability of freshwater resources is becoming universally depleted, leading to the requirement for a focused management strategy for treating and reusing wastewater. In particular for urban and developing areas, small scale decentralized treatment systems are becoming popular. The GROW (Green Roof-top Water Recycling System) constructed wetland is one such option that provides a solution without a permanent land requirement and offering medium to high treatment efficiency. The performance of the GROW system was monitored from November 2013 to April 2015 in treating greywater from the Krishna Student Hostel in IIT Madras. The performance of the GROW wetland cells were examined over four monitoring periods in Phase 1 namely: 1) start-up stage, 2) seasonal variation 3) change of flow rate and 4) change in organic fraction (26.8, 25.9 and 25.5 g COD/cubic meter/day respectively). In Phase 2, the plants and the filling materials were changed and the performance of GROW wetland cells were evaluated. The system was fed with greywater at a flow rate of 62, 70, 82, 100 and 120 L/day respectively with hydraulic retention time of 0.7–1.3 days. The samples taken from the inlet and the outlets of the GROW system were taken weekly and analyzed for the following parameters; pH, COD, BOD, TSS, TN, NO_3–N, TP, FC, SDS, PG and TMA. In the study, the overall removal efficiency was greater than 82% for all the parameters. The GROW wetlands reduced all the above mentioned parameters to within or closely to the USEPA standard limits for reuse. The reusable effluent water is named 'Green Water'.

1. Introduction

Increasing stress on the availability of freshwater sources worldwide has forced water providers to develop wastewater management strategies giving emphasis for recycling and reuse of treated wastewater. Wastewaters from households are classified into two types, i.e., i) greywater and ii) black water. Greywater includes wastes generated from bathroom sinks, baths or showers, washing clothes and possibly dishwasher except the wastewater from toilet whereas black water is the wastewater generated from toilets. Wastewater from dishwashers is usually excluded from greywater, due to high loading of fats/oils/greases (FOGs), organic content and bacterial contamination, which makes the wastewater difficult to degrade and handle (Jefferson et al., 2000; Avery et al., 2007). Greywater treatment and reuse is one of the efficient solutions which offer the largest potential of water savings, accounting for 50–80% of freshwater water consumption (Eriksson et al., 2002; Gross et al., 2007) in domestic purposes. Moreover, greywater is lightly polluted and requires less expensive treatment prior to non-potable reuse (Jefferson et al., 2000; Avery et al., 2007). There are various technologies available for treatment of greywater such as activated sludge process (ASP), membrane bioreactors (MBR), sequential batch reactor (SBR), rotating biological contractor (RBC), photocatalysis and electro coagulation (Merz et al., 2007; Masi et al., 2010). However, capital/infrastructure cost, social acceptance and power requirement may limit their application in rural and peri-urban areas in developing countries.

Treatment and reuse of greywater (as 'Green Water') for non-potable/secondary applications using various low cost less land intensive, sustainable and efficient technologies have been carried out in the past. Greywater was treated using a novel organic cation octadecyl trimethyl ammonium (ODTMA) with montmorillonite as a filtration unit along with a moving bed biological reactor for decomposition of part of the organic matter in the GW. The ODTMA

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complex was efficient in purifying GW due to its large surface area, positive charge and existence of hydrophobic domains (Rakovitsky et al., 2016). Another study used an anaerobic filter followed by ultraviolet disinfection system for the treatment and reuse of greywater from an airport in Brazil (do Couto et al., 2015). In-order to improve the green area of the city and to treat domestic greywater through a shallow horizontal subsurface constructed wetland that can be located in a household roof. A Wetland roof (WR) system was developed by Thanh et al. (2014). This system achieved an average COD removal efficiency of 77–78% or 20–28 kg COD/ha. day for both sunny and rainy days. The system was able to remove nutrients also effectively with a TN removal efficiency of 88–91% or 17–20 kg TN/ha. d, and a TP removal efficiency of 72–78% or 1.6 kg TP/ha d for different HLRs. Masi et.al. (2016) described the performance of a pilot installation of a green wall treating greywater from an office building in Pune, Maharashtra State, India. Green walls were filled with LECA® (lightweight expanded clay aggregate) and coconut fibers. COD removal efficiency of this system was in the order of 14–86% (Masi et al., 2016).

Constructed wetlands (CW) are also one of such systems considered as sustainable, cost effective and a viable treatment option for treating greywater for small communities. Over the past few years, CW has gained popularity due to its effectiveness, low capital investment and low cost of operation with less maintenance over the conventional systems for treating various types of wastewaters such as municipal wastewater, textile effluent and landfill leachate (Masi et al., 2010). Large number of studies was carried out on the treatment of greywater using constructed wetland (CWs). However, earlier researches mainly focused only on the treatment of grey water using CWs for the removal of organics, nutrients and pathogens (Avery et al., 2007; Gross et al., 2007; Frazer-Williams et al., 2008; Winward et al., 2008).

There are various types of constructed wetland classified based on their flow pattern; i) Horizontal subsurface flow constructed wetland, ii) Vertical subsurface flow constructed wetland and iii) Hybrid subsurface flow constructed wetland. The most commonly used hybrid flow CW is that in which the wastewater flows first into a horizontal flow CW (HFCW) and then to a vertical flow CW (VFCW) or vice versa, whereas in a few other studies hybrid systems are differentiated from other systems by introducing the baffles in the bed to make horizontal and vertical flow pattern in a single basin (Tee et al., 2012; Cui et al., 2015; Ramprasad and Philip, 2015). The advantage of the hybrid system is that the nitrogen can be nitrified completely in vertical flow CW and denitrified in horizontal flow CW (Sayadi et al., 2012). However, the disadvantage is that it requires large areas of land and complex construction and operation. To overcome the problem, a novel GROW constructed wetland (Green Roof-top Water Recycling System) was developed which is suitable for use in urban areas where ground space is limited

The GROW system consists of a series of troughs and weirs interconnected to form a plug flow regime for the wastewater to be treated and to utilize the entire bed for treatment. The advantage of the GROW system is that it can be utilized as a roof top garden in an area where space is a constraint. There are many studies showing the performance of GROW constructed wetland in treating pollutants from greywater (Avery et al., 2007; Gross et al., 2007; Frazer-Williams et al., 2008; Winward et al., 2008). The performance and working of the GROW system was originally monitored and subsequently studied at Cranfield University, UK by Avery et al. (2007), Memon et al. (2007) and Winward et al. (2008). A novel GROW system for treating 480 L/day of the hostel greywater with a hydraulic retention time of 18.6 h. The system consisted of a sequence of trough and weirs that were placed above the wooden frame on a pitched roof. The troughs were filled with expanded clay (size 0.1 m) and gravel chippings (size 0.2 m) and were planted with 8 varieties of native aquatic species. They found that the GROW system was most effective in the removal of suspended solids and turbidity (mean removal rates 91.2% and 98.2%, respectively). They also reported a 4.2 log reduction of total coliforms in the system. With a COD and BOD removal efficiencies of 59–80% and 84–92%, respectively, the treated water from the system was able to meet the stringent United States Environmental Protection Agency (USEPA) standard for water reuse (BOD < 10 mg/L). They also claimed that the GROW system performed better than horizontal and vertical flow constructed wetlands (Avery et al., 2007). A comparative studies on the life cycle impact assessment of GROW system with other three biological treatment systems like membrane bioreactors (MBR), membrane chemical reactors (MCR) and reed beds were done by Memon et al. (2007). They concluded that the GROW system performed best in most of the impact assessment categories and MCR appeared to be less environmentally friendly (Memon et al., 2007). Similar way, another study evaluated the presence of common pathogens (total coliforms, *E. coli*, *Enterococci*, *Clostridia* and Heterotrophs) in greywater and compared the performance of GROW, VFCW, HFCW, MBR and MCR in the removal of pathogens. These systems were operated continuously with a flow rate of 480 L/day with an HRT of 2.1 days. It was found that MBR system provided better quality treated effluent by meeting the stringent USEPA standard limits for reuse followed by VFCW, GROW, HFCW and MCR (Winward et al., 2008). Though there are many studies using GROW system for the treatment of greywater, all these studies were carried out in Europe (U.K) and mostly used the native substrate and plant species. Moreover, previous studies on GROW systems were conducted mostly at constant flow rate, hydraulic retention time (HRT) and organic loading rate (OLR).

In general constructed wetlands performances were affected by various factors such as climatic conditions, greywater characteristics, native plant species and substrate materials. The literature on GROW system were found to be mostly concentrated in the temperate maritime climate. The substrate (filling) material and plant species used in the earlier studies were mostly indigenous to the UK. Hence, it is necessary to evaluate the performance of the GROW system in different climatic conditions, vegetation patterns and greywater characteristics to determine the suitability of the system in other regions. Moreover, previous studies on GROW systems were conducted mostly at one particular flow rate, at constant HRT and at single organic loading rate (OLR). Information regarding the fate of surfactants and personal care products in GROW systems, is also lacking. Therefore, the present study focused on the evaluation of the performance of the GROW system in Indian tropical conditions and with native filling materials (sand, brick bat and gravel (1:1:1)) and 8 different plant species commonly available in India (*Canna indica, Canna flaccida, Canna lily – hybrid, Cardamina pratensis, Plectranthus amboinicus, Crossandrain fundibuliformis, Phragmiies australis, Solanum trilobatum*), at different flow rates (62, 70, 82, 100 and 120 L/day), and organic loading rates (26.8, 25.9 and 25.5 g COD/cubic meter/day). The study also evaluated the effect of seasonal variations, change of plant species and substrate materials on the performance of GROW system. The fate of surfactants in GROW system was also evaluated.

2. Materials and methods

2.1. GROW constructed wetlands

A novel constructed wetland system, Green Roof-Top Water Recycling System (GROW), was developed by Water Works UK Ltd., London, UK and was fabricated and installed in Krishna Hostel, IIT Madras, Chennai, India (GPS coordinates 12° 59′ 1.266" N; 80° 13′ 57.3852" E). Chennai lies on the thermal equator and features a tropical wet and dry climate with the temperature ranging from