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Surfactants and personal care products removal in pilot scale horizontal and vertical flow constructed wetlands while treating greywater

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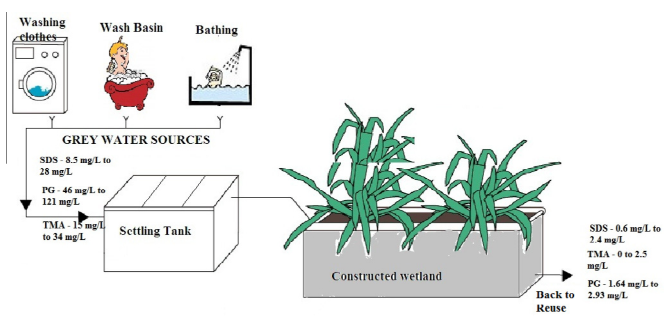
HIGHLIGHTS

- Horizontal and vertical flow wetlands were used for removing emerging pollutants.
- Effects of seasons, size, HRT and organic load on the performance were studied.
- Vertical system was more efficient compared to horizontal system for EC removal.
- Overall removal efficiencies of HFCW and VFCW systems were 94–99%.
- Treated water was meeting the USEPA standard limits for reuse as non-potable water.

GRAPHICAL ABSTRACT



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ABSTRACT

Studies were conducted on pilot scale horizontal (HFCW) and vertical subsurface flow constructed wetland (VFCW) systems for the treatment of greywater. The fate of emerging contaminants in these systems was evaluated. Sodium dodecyl sulphate (SDS), propylene glycol (PG) and trimethyl amine (TMA) were selected as the target emerging contaminants. Pilot plants were designed to treat 2.5 m^3/day of greywater generated in a student's hostel, with a hydraulic retention time (HRT) ranging from 8.9 days to 14.9 days. The greywater passed through a pre-treatment (settling tank) unit before entering the horizontal and vertical flow constructed wetlands (10.1 m × 2.55 m × 1.2 m). The substrate material in wet land systems was a mixture of sand, brick bats and gravel, and systems were planted with reed plant (*Phragmites australis*). Performance of systems was evaluated for the removal of organics, nutrients, bacterial contamination and emerging contaminants. Accumulations of emerging contaminants in soil and plant tissues were also studied. Performance was monitored over a year to study the effect of operating conditions such as hydraulic retention time, external organic load, and the seasons. It was found that the vertical flow system was marginally more efficient in treating the pollutants when compared to horizontal flow system. Removal efficiencies of SDS, PG and TMA in VFCW for different operating conditions were around 89%, 95% and 98%, respectively. In the case of HFCW, removal efficiencies were 85%, 90% and 95% for SDS, PG and TMA, respectively. The treated water from both the systems was meeting the USEPA standard limits for reuse.

1. Introduction

Rapid development and ever increasing production of chemicals during the last few decades has been resulting in release

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of numerous chemical compounds into the environment. The chemicals discharged into the environment include pharmaceuticals and personal care products (PCP's), endocrine disruptors, pesticides, surfactants and antiseptics. These chemicals are collectively referred to as emerging organic contaminants (EOC's or EC's) [1]. Approximately 15 million metric tons of surfactant are produced every year worldwide, out of which India uses 500,000 (i.e., 4.5%) tons [2]. Majority of these surfactants and PCPs enter the wastewater stream due to high solubility, without undergoing any metabolic changes. As a result, these compounds persist in the discharged environment for a long time, resulting in many adverse effects. Surfactants and PCPs are reported to be toxic to humans and mammals and long term exposure to these compounds may lead to cancer [3].

Wastewater is a combination of black water and greywater. It is advisable to treat greywater and black water separately in order to reduce water and pollution load on treatment systems [4]. Approximately 50% to 80% of domestic wastewater is greywater, arising from bathing and washing clothes. Makes up it contains high concentrations of surfactants. Most of the conventional wastewater treatment systems such as biological aerated filter (BAF) [5], sequencing batch reactor (SBR) [6], rotating biological contactor (RBC) [7], sand filtration, ultra filtration [8], coagulation and flocculation [9] and electro-coagulation [7] are effective in removing organic matter and nutrients to a large extent. However, they are incapable of removing many of the surfactant and PCPs [10]. In addition to excessive operation and maintenance cost, conventional systems require uninterrupted power supply [11].

Several studies have been carried out on sustainable wastewater treatment technologies such as constructed wetland (CW). It is a natural treatment process, involving complex interactions between soil, water, plants, microorganisms and prevailing flow conditions. CW technology has been recognized for its efficient recovery of water from diverse types of wastewaters [12]. Constructed wetlands have been widely applied successfully for treating different types of wastewater such as municipal wastewater, storm water [13], industrial wastewater [14] and agricultural runoff [15]. In the past, different wetland systems such as horizontal flow, vertical flow, hybrid flow, surface flow and sub-surface flow have been studied individually for the treatment of various organic pollutants, nutrients, solids and heavy metals [7], pathogen removal, some pharmaceutical and personal care products [16]. The horizontal flow system is the one where wastewater is flows from inlet to outlet in horizontal path through porous media, whereas in vertical flow system, the wastewater is fed from top of the bed and flows down through the porous bed and collected in an outlet drain [17].

Presences of relatively high concentrations of detergents are very common in greywater [18,19]. In most of the detergents, sodium dodecyl sulphate (SDS), an anionic surfactant (~29.22%); propylene glycol (PG), a non-ionic surfactant (~5%) and trimethyl amine (TMA), a cationic surfactant (~7.84%) make up for the maximum percent of constituents [20]. A few studies reported the degradation of SDS under aerobic conditions [21], anaerobic conditions [22] and in bio-filtration [23]. Studies have also reported SDS adsorption onto soil [18]. PG was removed by soil biodegradation [24]. Studies indicated the removal of TMA by adsorption onto wood ash and activated carbon [25], bio-filtration [26] and by obligate microbial degradation [27]. Though different types of constructed wetlands were studied for the removal of various pollutants, to the best of the authors' knowledge, no study was conducted for evaluating the performance of horizontal and vertical flow constructed wetland systems on a common platform, for treating surfactants found in greywater and their fate in such systems.

In this regard, it is essential to understand the fate of these compounds in CWS and their potential accumulation in the plants grown in CWs because many a times these plants are used as fodder. The main objective of this study was to evaluate the performance of horizontal and vertical constructed wetlands with respect to surfactants removal under different operating conditions. Studies were also carried out to quantify the amount of pollutants accumulated in soil and plants.

2. Materials and methods

2.1. Materials

2.1.1. Chemicals

Sodium dodecyl sulphate (SDS), propylene glycol and trimethyl amine were the compounds used as target pollutants in the present study. SDS (99% pure), glacial acetic acid, n-hexane (99.9% pure) and toluene (99% pure) were procured from Rankem chemicals, India. Acridine orange was obtained from Loba chemicals, India. PG and TMA were procured from Fischer chemicals and Merck chemicals, India, respectively.

2.2. Pilot scale constructed wetland

Two pilot scale reactors (HFCW and VFCW) were constructed in IIT Madras campus, Chennai, Tamil Nadu, India (12.9915°N, 80.2336°E). They were of equal size (10.1 m × 2.55 m × 1.2 m) with 1 in 100 slopes as shown in Fig. 1(a). The design of constructed wetland was based on the UN manual on design of constructed wetland [17]. The reactors had two portions: inlet/outlet layer, and main basin. The inlet/outlet layer was filled with gravel (20 mm size) to create a uniform flow into the basin; Main basins were filled with sand and brick bats with equal proportions as shown in Fig. 1(b). Twenty-seven sampling ports were provided in each bed to take samples at various depths, widths and lengths of the CWs as shown in Fig. 1(b) and S2 (a)–(d). *Phragmites australis*, commonly known as reed was used as the plant in the wetland.

2.3. Performance evaluation of pilot scale constructed wet land

Influent greywater was collected from bath rooms of one wing of Krishna Hostel, IIT Madras campus catering to about 60 students. This water consisted of used water from showers, washing machines and wash basins. Suspended solids from the greywater were removed in a staged setting tank. The settled greywater was then fed to the CWs. Samples were collected from inlet and all the sampling ports at periodic intervals for analysis. The performance of the systems was evaluated for different flow rates, organic loading rates (OLR) and hydraulic loading rates (HLR). Operational details of the CWs are presented in Table 1.

2.4. Analytical procedures

2.4.1. Environmental parameters

Parameters which were monitored to evaluate the performance of constructed wetlands include pH, total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), total nitrogen (TN), ammonia nitrogen (NH_4–N), nitrate nitrogen (NO_3–N), total phosphate (TP) and fecal coliform (FC). All the analyses were carried out as per standard methods for the examination of water and wastewater [28]. pH was measured using Eutech cyberscan PCD 650 multi parameter kit (Thermo scientific, Singapore); TSS was analyzed using gravimetric method (2540 D); BOD was measured by closed