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Research article

Studies on sustainability of simulated constructed wetland system for treatment of urban waste: Design and operation

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ABSTRACT

New system configurations and wide range of treatability make constructed wetland (CW) as an eco-sustainable on-site approach of waste management. Keeping this view into consideration, a novel configured three-stage simulated CW was designed to study its performance efficiency and relative importance of plants and substrate in purification processes. Two species of submerged plant i.e., *Potamogeton crispus* and *Hydrilla verticillata* were selected for this study. After 6 months of establishment, operation and maintenance of simulated wetland, enhanced reduction in physicochemical parameters was observed, which was maximum in the planted CW. The percentage removal (%) of the pollutants in three-stage mesocosms was; conductivity (60.42%), TDS (67.27%), TSS (86.10%), BOD (87.81%), NO_3-N (81.28%) and PO_4-P (83.54%) at 72 h of retention time. Submerged macrophyte used in simulated wetlands showed a significant time dependent accumulation of toxic metals ($p \leq 0.05$). *P. crispus* accumulated the highest Mn (86.36 μg g^{-1} dw) in its tissue followed by Cr (54.16 μg g^{-1} dw), Pb (31.56 μg g^{-1} dw), Zn (28.06 μg g^{-1} dw) and Cu (25.76 μg g^{-1} dw), respectively. In the case of *H. verticillata*, it was Zn (45.29), Mn (42.64), Pb (22.62), Cu (18.09) and Cr (16.31 μg g^{-1} dw). Thus, results suggest that the application of simulated CW tackles the water pollution problem more efficiently and could be exploited in small community level as alternative and cost effective tools of phytoremediation.

1. Introduction

Moving towards a clean, green and sustainable environment is an urgent need of the current world. Devastation of the nature, mainly due to globalization, industrialization and unprecedented urban expansion engender peril of water, air and soil pollution hazards, which severely affects the human beings and plants. In the succession of global increased toxic waste, contamination of water ecosystem worsened the situation. The aquatic systems are heavily polluted with different types of waste, including industrial effluents, urban and agricultural, animal wastewaters, leachates, sludges, pharmaceutical waste and mine drainage (Rai et al., 2013; Zhang et al., 2012) leading to the deterioration of water quality. Rai et al. (2015) reported that the contamination of water bodies was mainly due to discharge of untreated or partially treated waste emerging from various sources. Hence, water quality of river, lake and ocean gets very much contaminated and becomes unsuitable for drinking, bathing as well in agricultural practices. Therefore, it is vital to clean polluted water reservoirs. Since two decades, urban areas have invested billions of dollars to treat wastewater, but no fruitful results could be achieved to tackle water pollution effectively in a sustainable way. In this context, phytoremediation based constructed wetland (CW) technology could be a cost-effective and green alternative. Implementation of CW technology is not new and has been successfully used since decades to treat different types of waste employing a complex mixture of plant, substrate, water and microorganism (Babatunde et al., 2008; Langergraber et al., 2009; Ockenden et al., 2012; Rai et al., 2013).

CWs are designed to take advantage of naturally-occurring processes involving wetland vegetation, soils and associated microbial assemblages for environment cleanup (Kadlec and Wallace, 2009; Vymazal, 2007). Various designing criteria such as retention time, organic load, substrate type and flow of CW has been implemented to enhance the treatment efficiency (Kadlec and Wallace, 2009; Wu et al., 2014, 2015). Currently, hybrid wetland systems consisted of two stages of CWs, such as VF–HF CWs (Vertical flow-Horizontal flow CWs), HF–VF CWs (Horizontal flow-

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Vertical flow CWs), HF-FWS CWs (Horizontal flow-Free water surface CWs) and FWS-HF CWs (Free water surface-Horizontal flow CWs) (Vymazal, 2013) and multi-stage CWs (more than three stages CWs) are under operation for treatment of different type of wastewater, especially for removal of ammonia, nitrogen and phosphorus (Kadlec and Wallace, 2009). Aquatic vegetation significantly affects the performance efficiency of CW through adsorption, filtration, absorption, and secretion of organic acids, complexation, oxygen transport and providing suitable environment for microbial growth (Rai et al., 2015; Soda et al., 2012). Therefore, selection of plant species is a vital concern in CW designing because they should stay alive under the potential toxic effects of the influent and its inconsistency (Madera-Parra et al., 2015). For long term responses of CW, the substrate should have good hydraulic conductivity, which influences the clogging process of the system (Sani et al., 2013). Clogging of wetland directly depends on the hydraulic load and hydraulic retention time (HRT) of the CW as high load and HRT may lead to block the flow by deposition of a high amount of organic waste in the system. Thus, hydraulic loading rate and retention time are key factors in the success of CW. The substrate of CW provides habitat for microbial attachment, sorption, and movement of waste water and remediation of various pollutants, particularly of phosphorus and metals (Ju et al., 2014; Kadlec and Wallace, 2009). Diverse studies have revealed that submerged plants are better phytoremediator sp. in CW technology because they remove high organics and accumulation of different metals from the waste water (Wildeman and Cevaal, 1994). This may be mainly due to the pollutants enrichment condition at surface layer leads to healthier removal (Ran et al., 2004).

Pcrispus (Potamogetonaceae) and *Hverticillata* (Hydrocharitaceae) are perennial, fast growing aquatic macrophyte occur in a wide range of water and wastewater. To the extent of our knowledge, very little research has been done to treat pollutants in CW using submerged vegetation (Chen et al., 2012; Jing et al., 2010). The key objective of the experiments was to evaluate the inflow and outflow water quality of CW at different retention time and influence of substrate, hydraulic retention time and plants on the water-quality improvement in horizontal flow CW.

2. Material and methods

2.1. Experimental setup

The experiment was set up in the experimental field at CSIR-National Botanical Research Institute, Lucknow (26.80° N, 80.90° E) India having a warm humid sub-tropical climate. The treatment system was arranged in a continuous row, i.e., settling tank, unplanted and CW planted with submerged vegetation. Settling tank and horizontal flow CWs were arranged in the top to bottom position with settling tank on the top followed by CWs, so that wastewater flows horizontally by gravity through the CW. The height difference between settling tank and unplanted wetland was 10 cm. However, both the wetlands were kept in same height. The wastewater from unplanted CW allows to flow through the pipe in the planted CW. The schematic diagram of the CW has been shown in Fig. 1. The whole setup was kept for 6 months under regular observation for the proper functioning of the settling tank and CW.

2.2. Designing of settling tank

A quiescent type rectangular tank of size 162.5 × 57.5 × 70 cm (length × width × height) was made of concrete fitted and with inlet and outlet tightened with knob. The inlet was kept below 10 cm from the top in the side wall of the tank, and outlet was fitted above 3 cm from the bottom of the bed. Raw urban waste was supplied to the system through the inlet. The base of settling tank and planted and unplanted wetland was covered with PVC sheet to avoid percolation and reactions with concrete bed.

2.3. Designing of simulated CW

The CW was set up to simulate a horizontal flow wetland system. Mesocosm concrete rectangular tanks were constructed with the dimension of length × width × depth (162.5 × 57.5 × 70 cm) containing an inlet and outlet with controlling valve on the side wall. Wetland bed filled with supporting medium of 40 cm thick layer of sand (1–2 mm diameter); pea gravels (14–20 mm diameter) up to 15 cm and gravels (2–3 cm diameter) up to 10 cm height from top to bottom. Based on the system size, the hydraulic loading was 0.117 m^3 d^{-1}. Sequencing fills and draw-batch mode was applied to the influent. The flow rate was determined considering the surface area of wetland and controlled by using a gate valve through regulating the inlet and outlet flow with the help of beaker and a stop watch. Similar setup was also maintained for the planted CWs. The designing characteristic of the system has been shown in Table 1. The CWs were initially irrigated with tap water at regular intervals for 5 months for the growth and stabilization of the plants in CW.

Urban wastes were collected from discharge channel at Haridwar (India) and transported to the laboratory under cold conditions. After successful establishment of wetland, water samples were allowed to flow through the inlet of settling tank and

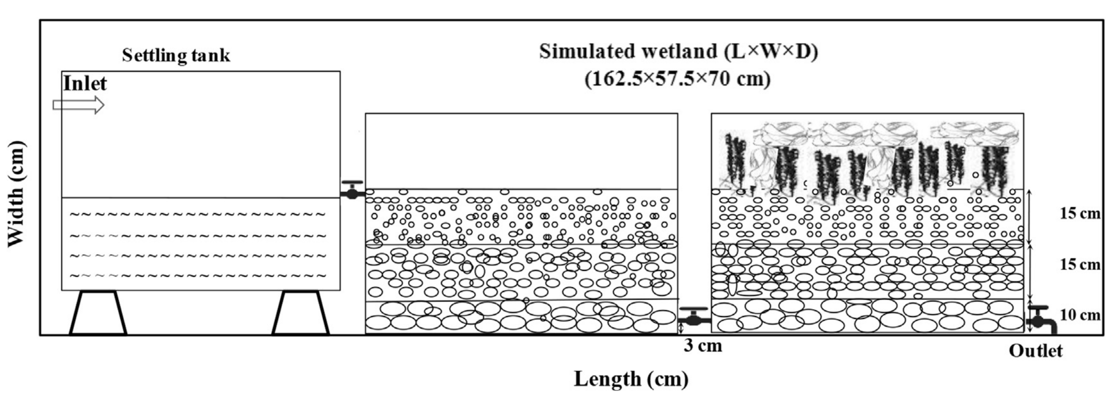

Fig. 1. Diagrammatic representation of three stage simulated CW.