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A comparative study of macrophytes influence on wastewater treatment through subsurface flow hybrid constructed wetland

Shama Sehar, Sumera, Sana Naeem, Irum Perveen, Naeem Ali, Safia Ahmed *

Department of Microbiology, Quaid-i-Azam University, Islamabad 45320, Pakistan

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ABSTRACT

Constructed wetlands (CWs) are engineered systems that attained much attention as a feasible wastewater treatment technology particularly for small communities. It has been widely considered that the type of vegetation and hydraulic retention time (HRT) are two key intervening ingredients which directly influence the performance of CW. This study aims to compare the efficiency of a laboratory scale sub-surface hybrid constructed wetland (SS-HCW) for domestic wastewater treatment planted with different plants species (*Brachiaria reptans* and *Trianthema portulacastrum)* at different hydraulic retention times. Our findings revealed that the CW planted with *T. portulacastrum* showed higher total suspended solids (TSS), total dissolved solids (TDS), SO_4^{2-}, PO_4^{3-}, NO_3^- and NO_2^- (70.03, 74, 76.59, 73.69, 80.40 and 81.46%) removal than *B. reptans* (58, 63.42, 53.98, 58.83, 70.34 and 62.64%) at 20 days HRT. Similarly a higher reduction in bacterial counts (5.10×10^3 CFU/mL) as well as fecal pathogens (265.5 MPN index/100 mL) was observed in *T. portulacastrum* than *B. reptans* at 20 days HRT. Moreover, the vegetated CWs demonstrated superior performance over unplanted control CWs. Therefore, the present study emphasizes not only the role of vegetation but also the selection of appropriate plant species in CWs for better performances.

1. Introduction

Despite of continuing depletion of existing water reservoirs throughout the world, the research on wastewater treatment and its utilization for human consumption have been receiving increasing attention. Therefore, the quest for green, cost effective and energy sustainable technologies is a subject of debate today. Among, current wastewater treatment technologies, the constructed wetland technology is considered as an eco-friendly, low cost technology with some distinct advantages such as; low operation and maintenance cost, as well as provide aesthetic value, generate usable plant biomass, and help support wildlife habitat (Poe et al., 2003; Solano et al., 2004; Carty et al., 2008; Shalaby et al., 2008). Constructed wetlands are effectively utilized worldwide for the treatment of various wastewater types such as; domestic wastewater (Vymazal, 2005; Song et al., 2009), food processing (Comino et al., 2011), fertilizer and chemical manufacturing (Domingos et al., 2007), tannery wastewater (Saeed et al., 2012), refinery effluent (Wallace and Kadlec, 2005), as well as for the elimination of emerging organic contaminants (Hijosa-Valsero et al., 2010; Ávila et al., 2013).

The constructed wetlands are formed by various beds loaded with inadequately sapped graded medium such as soil or gravel planted with vegetation coupled with microbial inhabitants that are essential for contaminants removal in surface water; groundwater or waste streams (EPA, 2000). Depending on the nature of flow, wetland systems are generally categorized into two major groups viz: surface flow and sub-surface flow. Further subsurface flow systems are categorized into horizontal and vertical subsurface flow wetland. Although, all of the mentioned systems are efficient in removing contaminants and pathogens from wastewater, however being possessing an elevated evaporation rate as compared to lagoons and ponds, the potential of reusable water in these systems is very limited. To overcome this concern, a configuration named as "hybrid CWs (combination of vertical and horizontal flow)" could be an appropriate alternate by having minimum water loss (Masi and Martinuzzi, 2007) and improved effluent quality with less total-N concentrations (Molle et al., 2008; Sayadi et al., 2012).

Rawal Lake is the largest source of water supply for the twin cities of Islamabad and Rawalpindi (population over 2 million) for human consumption and is getting polluted rapidly by the addition of domestic waste/sewerage from associated streams and

* Corresponding author. Tel.: +92 51 90643009.
E-mail address: safiamrl@yahoo.com (S. Ahmed).

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communities (residential colony and vicinity of Quaid-i-Azam University (QAU) Islamabad, Pakistan). Therefore, it is of great interest to treat the wastewater near their origin prior to its fraternization with lake water. Herein, in this work, we report lab-scale sub-surface flow hybrid constructed wetlands (SS-HCW) planted with *B. reptans* and *T. portulacastrum* and their treatment efficiencies were compared with varying hydraulic retention time. It was found that the presence of vegetations and their appropriate selection is essential to attain high treatment efficiency in CWs. Therefore, the similar strategy can be effectively utilized on larger scale (pilot scale) which could be a milestone towards preserving the largest water reservoir.

2. Materials and methods

2.1. Development and operational set up of SS-HCW

Two parallel laboratory scale SS-HCW systems were constructed comprised of a septic tank with loading capacity of 500 L and three rectangular operational units (length × width × height = 4 × 1.5 × 1.5 ft). The first two treatment units with subsurface vertical and horizontal flow respectively were composed of three layers lying one over the other (organic soil, 12.5 cm, sand, 15 cm, and gravel, 7.5 cm) and planted with *B.reptans* and *T. portulacastrum* in two separate experimental set up. Selection of plant was made on the fact that they were found growing naturally in sewage contaminated natural stream and tolerant enough for contaminants and saturated soil conditions. The third unit consisted of a sand bed that served the final polishing step from the water that received treatment from the first two units. Polyvinylchloride pipes (length, 125 in.; inner diameter, 2 cm) were used to interconnect four units that were sequentially placed at decreasing levels (1 ft) to enable natural flow of water under gravity. Flow rate of water among different units was regulated by valves and nozzles. Before subjected into working conditions, the middle two units were kept soaked with fresh water for 3–4 weeks in order to acquire saturated growth of plants and associated microbial community in the rhizosphere, sand and gravel bed. This helped in the establishment of a compact bed suitable for wastewater treatment. SS-HCW was operated with different hydraulic retention times of 4, 8, 12, 16, 20, 24 and 28 days (from April 2012 to July 2013). Temperature was continuously monitored during the entire study by using thermometer and was found to be in the range of 30–45 °C. Similar system was developed without any vegetation that serves as a control. A schematic representation of the overall treatment process is shown in Fig. 1.

2.2. System operation: Treatment of wastewater

Domestic wastewater samples were collected in pre-washed (with detergent dilute nitric acid and doubly deionized water respectively) polyethylene bottles from residential colony and nearby areas and given a retention time of almost 3–4 h in the septic tank to allow settling of suspended particles and particulate material. After sedimentation, this partly treated wastewater was then subjected to treatment in the subsequent units of SS-HCW. During the course of the functional phase of wetland system, temperature was regularly monitored. Water samples were collected from each processing unit at different HRTs (4, 8, 12, 16, 20, 24 and 28 days) and analysed for various physico-chemical and microbiological parameters.

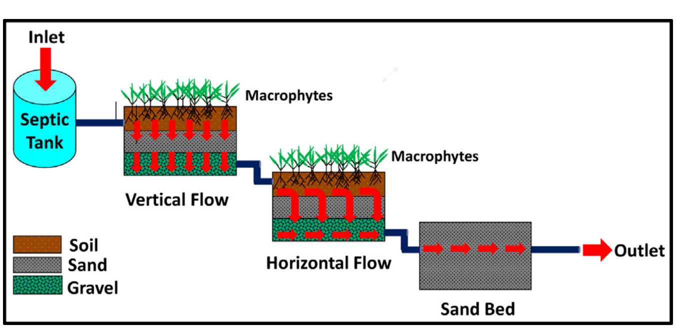

Fig. 1. Schematic illustration of subsurface hybrid constructed wetland (SS-HCW).

2.3. Physico-chemical analysis

Physico-chemical parameters were determined by following American Public Health Association (APHA) Standard Methods (APHA, 2005). Organic contaminants including biological oxygen demand (BOD) was measured by 5-day BOD test (following 5210 B standard methods) and chemical oxygen demand (COD) by kit method; (high range 14541 and low range 14560 CSB/COD kits, (Merck, Germany)). Total dissolved solids (TDS) and total suspended solids (TSS) were determined by standard methods 1540 C and 2540 D respectively. Nitrates, nitrites, phosphates and sulfates were determined by standards methods; 4500 NO_3–N, 4500 NO_2–N, standard method 4500-P and 0375 Barium chromate respectively.

2.4. Microbiological analysis

Domestic wastewater was subjected to microbiological analysis through colony forming unit (CFU/mL) and most probable number technique (MPN index/100 mL) of pathogenic indicators i.e. fecal coliforms and *Enterococcus faecalis* as per guideline of Bergey's Manual of Determinative Bacteriology (Holt et al., 1994).

Conventional serial dilution method was employed for CFU/mL of bacterial colonies in the influent and effluent samples. Wastewater samples were serially diluted in sterile water up to 10^{-10} and these dilutions were spread plated on nutrient agar plates and incubated at 37 °C. After 24 h of incubation, the colonies appeared were enumerated by colony counter, and CFU of each colony was then calculated as follows:

CFU/mL = number of colonies × dilution factor/inoculum size.

For determining the MPN index of pathogen indicators ((fecal coliforms, *E. coli*, *Salmonella*, *Shigella*, *Klebsiella* sp., *Enterobacter* and *Citrobacter*), untreated (influent) and treated (effluent) wastewater samples were incubated at 42.2 °C for 24–48 h in MacConkey's broth using multiple tube technique having inverted Durham tubes. Positive tubes were subcultured on MacConkey's agar (MacA), Nutrient agar (NA) and Mannitol salt agar (MSA) plates and incubated at 37 ± 2 °C for 24–48 h. Positive isolates showing growth of bacterial colonies were confirmed by microscopy and checked for total count.

2.5. Microbial profiling of rhizosphere of B. reptans and T. portulacastrum

For determination of bacterial diversity colonizing the rhizosphere of *B. reptans* and *T. portulacastrum* planted in SS-HCW, 1 g soil sample was collected. Different dilutions of the order 10^{-3}, 10^{-5} and 10^{-7} were prepared. From each dilution, 0.1 mL inoculum was pipetted and inoculated onto nutrient agar plates by spread plate technique and plates were incubated for 24 h at 37 °C. After incubation, different types of colonies on nutrient agar plates were distinguished by morphological characteristics. For the purpose of obtaining pure cultures, different colonies were further sub-