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Highway runoff treatment by lab-scale horizontal sub-surface flow constructed wetlands

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ABSTRACT

In this study, lab-scale horizontal sub-surface flow constructed wetlands were experimented to assess their removal efficiency of highway runoff pollutants under different hydraulic conditions. Constructed wetland units with cobble-stone and broken-stone material as filter media were planted with common reed (*Phragmites* spp.) plants. Water samples collected from inlets and outlets of the wetland units were analyzed to determine total suspended solids, COD, ammonia-nitrogen, total nitrogen and total phosphorus. The results show that removal efficiency was quite low with cobble-stone filter media, whereas constructed wetland units with broken-stone filter media led to higher removal efficiency for SS (73.54%), COD (55.48%), NH_3-N (81.89%) and TP (57.08%), respectively, but had a TN removal of −29.29% (increase in effluent). Results indicate that overall broken-stone filter media demonstrated better performance than cobble-stone filter media because broken-stone has larger specific surface area.

1. Introduction

Water pollution by various point or non-point sources has become a very critical environmental issue in recent years. Specifically, highway runoff has become a major pollution source to its surrounding environment with the rapid urban development (Kayhanian et al., 2003 and 2007). Since highway runoff consists of different types of pollutants, considerable studies have been done on treatment and management of highway runoff with different structural best management practices (BMPs) (Terzakis et al., 2008; Kalainesan et al., 2009). Of many BMPs, constructed wetlands (CWs) are highly effective control measures for treatment of storm water runoff from highways (Vymazal, 2009). It is well accepted that the performance of CWs is influenced by their area, length to width ratio, water depth, rate of wastewater loading and the retention time and wetland plants (Pant et al., 2001). However, the main advantages of CWs, i.e., high pollutant removal efficiency and lower operating and maintenance costs, can only be retained by (i) carefully selecting the filtration material, (ii) even distributing the storm water across the wetland surface, and (iii) operating the CWs with optimum hydraulic loading rate (HLR) (Dong et al., 2005; Vymazal, 2007; Akratos and Tsihrintzis, 2007; Siriwardene et al., 2007).

A plenty of research work has been carried out on pollutant removal efficiency of various filter materials, e.g. gravel, sand, boxite, zeolite, limestone, flyash and shale, etc. (Kayhanian et al., 2007; Dong et al., 2005). The gravel filters are very efficient in removing sediment from storm water but are prone to clogging; therefore their performance usually decreases with time, and high incidence of failure has been also found in these systems due to clogging (Siriwardene et al., 2007). Currently, sufficient information is not available on how filter media affect the performance of CWs for storm water treatment. On the other hand, unlike the developed countries, research on using BMPs for highway runoff treatment in developing countries like China has been very limited (Huang et al., 2006; Zhao and Qiu, 2004). Hence, the objective of this study was to evaluate the performance of two lab-scale horizontal sub-surface flow CWs (HFCWs) for highway runoff treatment under the influence of different filter media (i.e., broken-stone and cobble-stone) and HRTs but similar HLRs.

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2. Methodology

2.1. Storm water sampling site and sample collection

Highway runoff samples were collected from the site chosen near to Nanjing city of China. Nanjing is the capital city of Jiangsu province of China and located at 32°03′ N latitude and 118°47′ E. It has a humid subtropical climate and seasons are distinct, with usually hot summer and plenty of rainfall throughout the year. The average precipitation falls 115 days out of the year, and the average annual rainfall is 1062 mm. Heavy rainfall usually occurs between mid of June to July/August. The annual mean temperature is 15.9 °C, and ranges from 3 °C in January to 28.3 °C in July. The Lukou viaduct section of Nanjing airport express highway was selected for highway runoff collection during various rainfall events in 2009. The material used in construction of this four lane highway was mainly asphalt material. The average hourly traffic flow (AHTF) is 270 vehicles, whereas the average daily traffic flow (ADTF) is around 38,400 vehicles (Car – 18,200, bus – 8200 and heavy truck – 12,000) and the traffic count was consistent throughout the year (Zuo et al., 2011). Total catchment area is around 960 m^2, which is mainly used as residential, transportation and arable purposes. The rainfall events were selected randomly. The highway runoff was collected during various rain events with the help of runoff collection pipes and stored in a settling tank before transferred to laboratory for further use (e.g., as the feed of CWs and for analysis). Simultaneously, rainfall characteristics were recorded by JS-2 Siphon Rain Gauge (Tianjin Meteorological Instrument Co., China). The distance between rain gauge and sampling site was approximately 500 meters.

2.2. Lab-scale CWs

Two lab-scale HFCWs made with Plexiglas (80 cm in length, 40 cm in width and 65 cm in height) were constructed at the Southeast University Research Center for Municipal Wastewater Treatment (Fig. 1). All wetland units were planted with common reed plants (*Phragmites australis*) prior to start the experimental work. Two sets of HFCW units are referred here as HFCW-BS and HSCW-CS (Table 1). HFCW-BS refers to the wetland unit filled with broken-stones media (BS) (media broke into different size), with a matrix composition being a top soil layer (silt) of 15-cm thickness. Below the top soil layer, CW unit was filled with different sized broken-stone filter media with a lower 15-cm section with fine particles (1–2 cm in diameter), followed by a 10-cm layer of middle size particles (2–4 cm in diameter) and the lowest 10-cm layer having large particles (6–8 cm in diameter). HFCW-CS refers to the wetland unit filled with cobble-stone (CS) filter media. As shown in Table 1, it had a similar substrate arrangement scheme as that used in HFCW-BS (e.g., the lowest layer with a CS matrix size of 6–8 cm). Highway runoff was fed into the two CWs units at similar hydraulic loading rates (Table 1). For each wetland unit, control valves were setup at 10 cm above the bottom to control the influent flow (i.e., to separate the perforated plate and treatment area in HSSF-CWs) and at the exit to monitor the effluent flow. The flow rate was calculated by the volume of the water passing through the given surface area per unit time. A water level regulator was setup at 20 cm height to regulate the water level. The devices, storage tank and metering pumps were placed indoor in order to avoid interference with the external environment. The runoff was first collected into a storage tank through runoff collection pipes and stored there for 2 h to simulate the pre-sedimentation prior to use in CW units. A total of 23 samples were collected during various rainfall events in the present investigation. The porosity of BS and CS substrates was 0.37 and 0.36, respectively. The influent flow rates were set to 2.96 and 2.88 L/h, whereas hydraulic loads were

Table 1
Process parameters implemented in horizontal sub-surface flow constructed wetlands (HFCWs).

Parameters	HFCW-CS	HFCW-BS
Filter media	Cobble-stone	Broken-stone
Filter media diameter (cm) in substrate layers below top 15-cm soil layer	1–2/2–4/6–8	1–2/2–4/6–8
Porosity	0.37	0.36
Hydraulic conditions		
Water flow rate (L/h)	2.96	2.88
Hydraulic load (cm/L)	29.6	28.8
Slope gradient ($\Delta H/\Delta L$)	($\Delta H/\Delta L$) = 1/10	($\Delta H/\Delta L$) = 1/10
Length × Width × Height (cm)	80 × 40 × 65	80 × 40 × 65
Average pollutants Loading ($Q \times C_0$) (mg month^{-1})	79,285.8	77,185.5

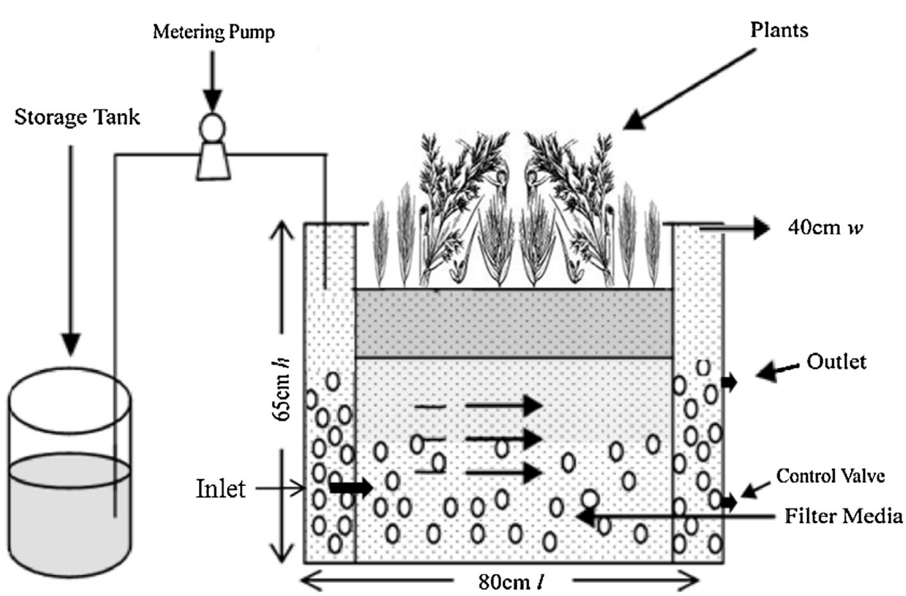

Fig. 1. Flow diagram of horizontal sub-surface flow constructed wetlands (HFCWs).