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Hybrid constructed wetlands for highly polluted river water treatment and comparison of surface- and subsurface-flow cells

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ABSTRACT

A series of large pilot constructed wetland (CW) systems were constructed near the confluence of an urban stream to a larger river in Xi'an, a northwestern megacity in China, for treating polluted stream water before it entered the receiving water body. Each CW system is a combination of surface- and subsurface-flow cells with local gravel, sand or slag as substrates and *Phragmites australis* and *Typha orientalis* as plants. During a one-year operation with an average surface loading of 0.053 $m^3/(m^2 \cdot day)$, the overall COD, BOD, NH_3-N, total nitrogen (TN) and total phosphorus (TP) removals were 72.7% ± 4.5%, 93.4% ± 2.1%, 54.0% ± 6.3%, 53.9% ± 6.0% and 69.4% ± 4.6%, respectively, which brought about an effective improvement of the river water quality. Surface-flow cells showed better NH_3-N removal than their TN removal while subsurface-flow cells showed better TN removal than their NH_3-N removal. Using local slag as the substrate, the organic and phosphorus removal could be much improved. Seasonal variation was also found in the removal of all the pollutants and autumn seemed to be the best season for pollutant removal due to the moderate water temperature and well grown plants in the CWs.

Introduction

With intensive urbanization and rapid industrialization in recent decades, surface water pollution has become a serious issue in China (Bu et al., 2010; Guo, 2007). Because of the insufficient wastewater treatment systems, large quantities of treated and untreated domestic wastewater and industrial effluent were discharged directly or indirectly into urban streams which lead to the pollution of the ultimate receiving water body. According to the latest statistical data (MEP, 2011), 39% of the rivers in China are polluted and unsuitable as source water for drinking water production. River water pollution is much more serious in the urban area where many streams appear black and malodorous (Qu and Fan, 2010). In northwestern China, due to dry climate and insufficient rainfall, treated and/or untreated wastewater may become the main flow in the dry season or even throughout a dry year. Therefore, finding appropriate ways for improving urban river water quality is highly desirable in many cities.

It has long been recognized that wetlands can remove pollutants in natural and/or engineered systems. The constructed wetlands (CWs), as artificial units to simulate the processes of the natural wetlands in an enhanced manner, have been well developed since later 1980s (Vymazal, 2009). Due to their low cost, simple operation and maintenance, and favorable appearance, CWs are considered to be a very promising technology for various wastewater treatments as long as the land is available for construction (Shutes, 2001). According to the local condition and treatment requirement, the CWs can be constructed in different types such as free water surface (FWS) and subsurface flow (SSF) wetlands (IWA, 2000). In fact, each type of the CWs

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has its own advantage and disadvantage. Therefore, there has been a growing interest in the development of hybrid systems in which different types of CWs are combined to complement each other to achieve more effective removal of pollutants for treating various wastewaters (Vymazal, 2008; Tuszyńska and Obarska-Pempkowiak, 2008; Bulc, 2006; Comino et al., 2011) and for treating polluted river and lake waters (Jing et al., 2001; Wu et al., 2011; Cui et al., 2011; Dong et al., 2012).

The treatment of polluted river water by CWs is usually for a reduction of the pollutant loading from a smaller tributary to a larger stream. The most possibility to build the CWs for polluted river water quality improvement is to make use of the flood lands near the confluence of the tributary to the main stream for CWs construction. Due to the uncertainties in the polluted river water quality, the design and operation of the CWs in such a case have to deal with circumstances much different from the CWs for wastewater treatment. This is the case of the present study which was conducted for investigating the feasibility of using CWs to treat the water from a polluted urban stream for reducing its pollutant loading to a river that receives the stream flow. For this purpose, pilot CWs combining FWS and SSF cells were constructed and operated. The objective of the study was to gain knowledge and experiences for the design and construction of the full scale CWs to be constructed for practical operation.

1 Materials and methods

1.1 Polluted condition of the urban stream

Zaohe River, the urban stream investigated in this study is located in the west suburb of Xi'an, a megacity in northwestern China where insufficient rainfall and dry climate result in serious problem of water shortage. With a basin area of 135 km^2 and a total length of 22.3 km, the natural base flow in the Zaohe River is very limited and its main function at present time is an urban drainage channel to receive effluents from several domestic wastewater treatment plants all the time and storm water in the rainy days. Similar to many cities nowadays in China, the provision of urban infrastructure including sewerage works can not always meet the needs of urban development in Xi'an. For this reason, untreated domestic wastewater and even industrial wastewater from small industries are also discharged into Zaohe River. **Figure 1** shows the water quality monitoring results in the one-year study period from November 2010 to October 2011 at the entrance of

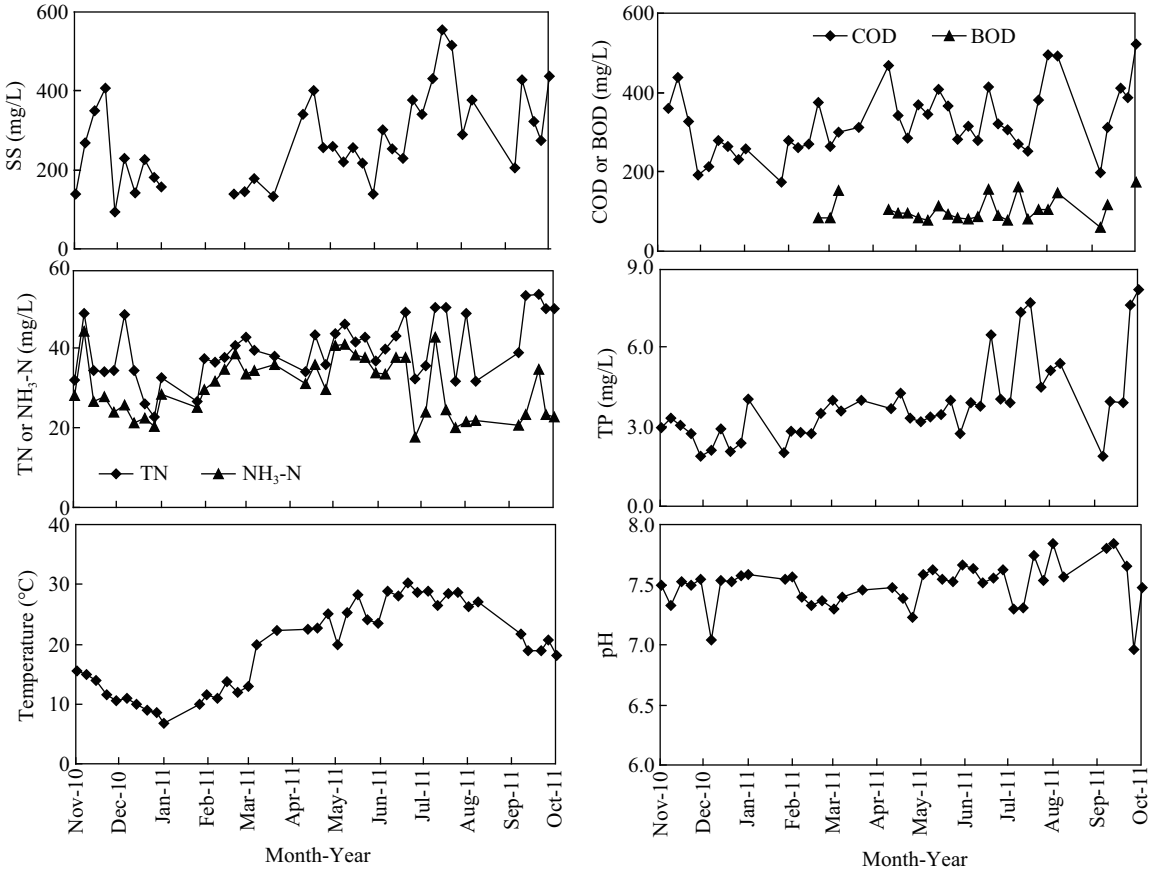

Fig. 1 Water quality of the Zaohe River during the one-year study period from Nov 2010 to Oct 2011.