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Design parameters affecting metals removal in horizontal constructed wetlands for domestic wastewater treatment

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ABSTRACT

As regards constructed wetlands (CWs), there is a great deal of research on metals removal, although comparison of different parameters under the same conditions is scarce. The aim of this study was to determine the most important factors affecting the removal efficiency and dynamics of metals and metalloids according to different configurations of horizontal CWs. An experimental plant, including the most commonly used CWs, was analysed for several metals (Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, Sn and Zn). Arsenic, which was under the detection limits at the influent, presented a release in those wetlands with subsurface flow (SSF) and followed the same pattern as iron and manganese. The presence of vegetation and flow type were key design factors affecting metals removal from urban wastewater. Free water surface (FWS) flow provided favourable conditions for the removal of As, Fe and Mn, which are sensitive to redox changes, whereas SSF slightly enhanced the removal of other metals, such as Cu or Pb. On the other hand, vegetation was not able to maintain steady oxidised conditions to guarantee redox dependent metals removal by combination with oxides in SSF systems. In contrast, constant reduced conditions promoted the long-term removal of metals by sulphide combination and precipitation.

1. Introduction

Constructed wetlands (CWs) are widely known for their efficient removal of conventional pollutants and many authors have focused their studies on the effect of different design parameters in wastewater (WW) treatment, such as vegetation, aeration, depth or substrate (Chazarenc et al., 2009; García et al., 2005; Seeger et al., 2013). However, priority and emerging pollutants have been assessed less, although they are of special interest due to their toxicity in final disposal watercourses. In that sense, metal and metalloid concentrations are supposed to be low in urban WW compared to industrial WW (Henze, 2002), but current legislation considers some of them as priority hazardous substances (Council of the European Communities, 2008; European Commission, 2001).

CWs encompass different treatment mechanisms depending on design parameters, such as flow type, vegetation, dimensions and shape or operation mode. Environmental conditions within the beds influence wastewater treatment processes (García et al., 2010; Hijosa-Valsero et al., 2010) and metals are not excluded from this influence. The removal (or dynamics) of metals from inlet to outlet of a wetland is produced by physicochemical (including filtration, sorption or precipitation) and biological processes (both by microbial activity and plant uptake) (Kadlec and Wallace, 2009). All these removal mechanisms involve the accumulation of most metals in the system compartments: either sediment, plants or water (Lesage, 2006). Although several experiments have been aimed at determining plant species with high accumulation capacity (Liu et al., 2007; Maine et al., 2009), many authors confirmed that metals accumulate mainly in wetlands sediment (Arroyo et al., 2013b; Lesage et al., 2007; Ranieri and Young, 2012). Usually, immobilisation and accumulation of metals inside the bed depends on its redox state, which determines the solubility of many metals (Kosolapov et al., 2004; Ye et al., 2013). Under reducing conditions, sulphide precipitation seems to be an important removal mechanism for iron, lead and nickel, whereas in oxidised conditions these metals tend to combine with hydroxides (Kadlec and Wallace, 2009). In intertidal marshes, a hydrological regime has been identified as one of the key factors affecting mobility and availability of metals (Du Laing et al., 2008a, 2009a). The water table level greatly affects redox potential within

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the sediment and also Fe and Mn oxide reduction (Du Laing et al., 2008b).

The design configuration of CWs strongly determines the environmental conditions within the bed, especially the overall redox state (Pedescoll et al., 2013a). Consequently, differences in metal dynamics would be expected according to the design configuration. Arroyo et al. (2010) found differences in metals removal in a Hierarchical Mosaic of Artificial Ecosystems (HMAE®) for municipal wastewater treatment depending on the treatment unit considered. Previous experiences demonstrate the effect of vegetation (Liu et al., 2007; Maine et al., 2009; Marchand et al., 2010), substrate (Arroyo et al., 2013a), shape (Galletti et al., 2010), hydraulic loading rate (HLR) (Dotro et al., 2012; Pimpan and Jinddal, 2009; Ranieri and Young, 2012) or flooding regime (Du Laing et al., 2007) in the performance of wetlands for metals and metalloids. However, there is a lack of studies covering the comparison of a wide variety of CW designs in order to determine the best configuration for trace element removal. In fact, most studies only evaluate two experimental conditions. Therefore, the aim of this study was to explore the removal efficiency and dynamics of metals and metalloids using eight different configurations of horizontal constructed wetlands (HCWs) and to determine the most important factors affecting their performance. For this purpose, an experimental plant, including the most commonly used HCWs, was assessed for several metals (Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, Sn and Zn). Design parameters such as vegetation, plant species, flow type and hydraulic loading rate were evaluated under the same climatic conditions and influent wastewater characteristics.

2. Methods

2.1. Experimental device

An experimental plant, placed inside the facilities of the León wastewater treatment plant (WWTP) in the northwest of Spain, was used for this study. The plant consisted of eight mesocosm-scale CWs (80 cm wide, 130 cm long and 55 cm high), differing from each other in their design configuration, so that pairwise comparisons between wetlands differing in only one design parameter could be made as shown in Fig. 1. CW1 and CW5 were constructed as soilless wetlands with macrophytes (*Typha angustifolia* and *Phragmites australis*, respectively) growing under hydroponic conditions. In these two wetlands, water depth was 30 cm and plastic mesh garden cylinders kept plant species upright. CW2, CW3 and CW4 were designed as free water surface (FWS) systems, with 25 cm of siliceous gravel (d_{60} = 7.3 mm) and 50 cm water depth (25 cm of water ponding on the gravel surface). CW2 was a strict FWS with inlet and outlet pipes located on the surface of the wetland. In CW3 and CW4, the outlet pipe was placed at the bottom of the container, thus forcing the water to flow through the subsurface. CW2 and CW3 were planted with

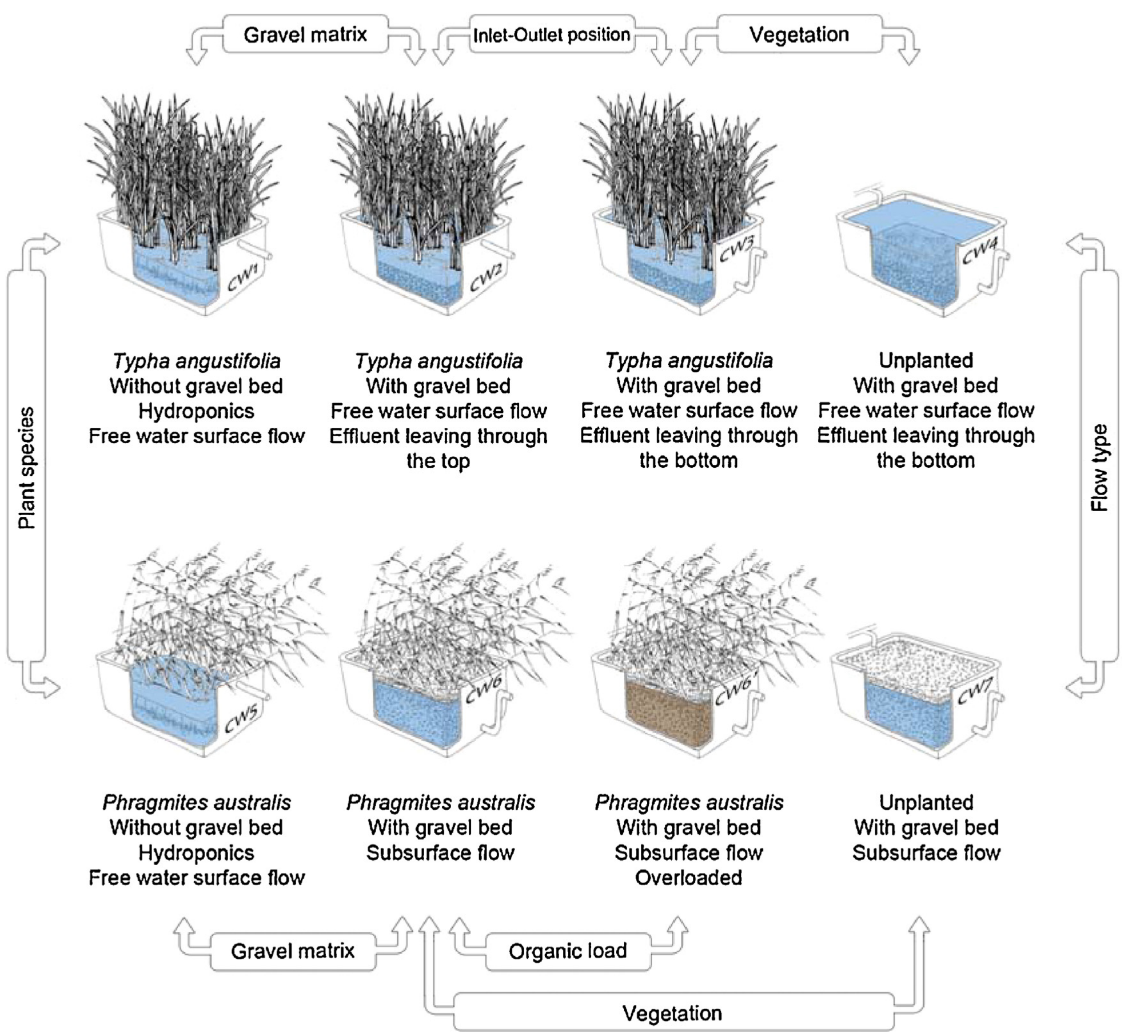

Fig. 1. Configuration of the experimental plant and the effects evaluated among wetlands.