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Performance of constructed wetland applied for domestic wastewater treatment: Case study at Boimorto (Galicia, Spain)

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ABSTRACT

The study aims at evaluating the performance of a horizontal subsurface flow constructed wetland used for secondary treatment of domestic wastewater since May 2011 at Galicia (Spain). A septic tank was used as primary treatment. The wetland consists of two cells in parallel: cell-A with 350 m^2 and cell-B with 280 m^2, constructed with a depth of 0.6 m, filled with gravel of 30 mm of average size and planted with common reeds. The performance of wastewater treatment was controlled from June 2011 to September 2015. The rural agglomeration is served by a gravity sewer system with high rates of infiltration/inflow during wet weather. Thus, concentration and flow rate of wastewater have high seasonal variability. Average primary effluent BOD_5, COD, suspended solids (TSS), total nitrogen (TN) and total phosphorous (TP) concentrations (in mg/L) were: 105, 197, 43, 29 and 3.4, respectively. Meanwhile, average secondary effluent BOD_5, COD, SS, TN and TP values (in mg/L) were: 19, 44, 12, 14.3 and 1.9, respectively. A 2.2 log unit reduction for faecal coliforms was observed in the global system. The wetland required to be harvested at the end of each October. The sludge produced by the septic tank has not yet required to be removed. The wetland system presented no problems for vectors or nuisance odours.

1. Introduction

Constructed wetlands (CWs) are an appropriate technology for areas where inexpensive land is generally available and skilled labour is less available (U.S. EPA, 2000b). CWs are engineered wetlands that have saturated or unsaturated substrates, emergent/floating/submerging vegetation, and a large variety of microbial communities that are purposely built for water pollution control (Saeed and Sun, 2012). Biotic and abiotic purification mechanisms of CWs are based on the following processes (Gumbricht, 1993; Hiley, 1995): (a) mechanical screening and sedimentation, (b) microbial degradation, (c) biochemical nutrient removal of plant rhizomes, (d) adsorption through ligand exchange, (e) precipitation and chemical fixation of reactive soil ingredients. CWs have been employed for four decades for the treatment of sewage, stormwater, combined sewer overflows, farmyard runoff, acid mine drainage and industrial wastewater such as landfill leachate and dairy wastewater (Dittmer et al., 2005; Mustafa et al., 2009; Sheoran and Sheoran, 2006; Wood et al., 2008; Wu et al., 2015).

Around the world many of the CWs are designed with horizontal subsurface flow (HSSF). HSSF-CWs are more appropriately applied behind a process designed to minimize suspended and settleable solids, such as a septic or Imhoff tank (Corbella and Puigagut, 2015; Mara, 2006). In Europe, *Phragmites australis* (common reed) are the preferred plants for these systems (IWA, 2000). *Phragmites* have several advantages since it is a fast growing hardy plant and is not a food source for animals or birds.

The use of constructed wetlands is an eco- technology especially beneficial to small populations (in Europe usually defined as treating less than 2000 population equivalents, PE) that cannot afford expensive conventional treatment systems. Human activity in rural areas is considered to be very negative regarding water quality (Mander and Chazarenc, 2015). HSSF-CWs have been proven to constitute an alternative cost- effective technology to conventional wastewater treatment plants (WWTPs) in the context of small and rural communities (Ávila et al., 2013; Solano et al., 2004). Generally, the wetlands can be constructed with local materials which lower the construction cost (Zurita et al., 2009). Evaluation of the long-term performance of HSSF-CWs in the Czech Republic has indicated

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that removal of organics and TSS is very effective; efficiencies are steady throughout the whole year and are neither affected by seasonal change nor the length of operation (Vymazal, 2011; Vymazal and Brezinová, 2014). Moreover, in a study of a pilot HSSF-CW it has been observed that the removal of TN is significantly affected by seasonal temperature changes in a moderate climate (Kuschk et al., 2003).

In rural areas of Galicia (Spain) about 700 agglomerations with less than 1000 PE (accounting about 180,000 PE) have no WWTP. The biggest requirement is to construct WWTPs in agglomerations with 100–400 PE. CWs are effective treatment systems that can be very appropriate in rural areas of Galicia because they are simple technology and involve low operational costs. So far in Galicia, the CWs have been implemented poorly, but beginning to be considered as a viable alternative. Therefore, it is very important to evaluate the performance of CWs in operation to feed the design and O&M criteria back. Thus, in order to remove organic matter and TSS contained in domestic wastewater of rural agglomeration Dormeá (Boimorto, Galicia) a WWTP composed of a septic tank for primary treatment and HSSF-CW as secondary treatment was constructed. For sizing the required wetland area, the classical model of plug-flow first order was used (Kadlec and Wallace, 2009). The aims of this case study include: (1) assessing design parameters at full-scale of HSSF-CWs; (2) evaluating the seasonal efficiency of the wetland, (3) assess compliance with the discharge limits set to effluent of WWTP, (4) propose criteria for the quality control of the discharge of a small WWTP based on wetland process as secondary treatment, and (5) to recommend best practices in operation & maintenance (O&M) of these systems. It is noteworthy that one of the objectives of this case study (objective 4) has been to demonstrate that analyzing grab samples of the effluent of a HSSF-CW is satisfactory to assess the performance of the process.

2. Materials and methods

2.1. WWTP description

The WWTP is located in the rural agglomeration Dormeá. The site elevation is 480 m, humid oceanic climate with an annual rainfall between 1200 and 1900 mm. In the system of sanitation (sewerage and sewage treatment plant) the wastewater flows to gravity. The WWTP aims secondary treatment of domestic wastewater generated by 120 PE. According to Galicia legislation (Lei 9, 2010) the WWTP Dormeá have the following discharge limits: $BOD_5 \leq 40$ mg/L; COD ≤ 160 mg/L; and TSS ≤ 80 mg/L.

The liquid-processing train includes a dual-chamber septic tank with a total volume of 45 m^3 which serves for roughing and primary treatment, and HSSF-CW as secondary treatment. Each of the two chambers of the septic tank is provided with a pine-bark filter to eliminate nuisance odours. The substrate wetland consists of gravel with an average size of 30 mm, a depth of 60 cm and porosity of 50%. HSSF-CW is compartmentalized into two cells in parallel. Due to the geometric characteristics of land parcel, the wetland cell surfaces are not identical: one occupies 350 m^2 (cell-A) and the other 280 m^2 (cell-B), both planted with common reed (Fig. 1). Half the daily flow was treated for each cell of the wetland. Thus, cell-B treated a hydraulic load rate 25% greater than the cell-A.

The WWTP Dormeá has no sludge-processing train. Sludge is produced by the septic tank. Properly sized tanks can accumulate sludge for at least three years (U.S. EPA, 2000a). Until September 2015, after 53 months of operation, it was not necessary to remove sludge from the septic tank. The septage treatment will be carried out in the neighbouring WWTP possessing sludge-processing train. The constituents of septage are similar to domestic sewage, even though septage is stronger and more concentrated (U.S. EPA, 1999).

Fig. 1. Constructed wetland at Dormeá, Boimorto (Spain). Photo taken in June 2015.

2.2. Flowrate measurement, water quality analyses and sampling

Intermittent delivery of effluent (pulses) from the septic tank into each cell of the wetland was performed using a tipper-like device with a similar operation to that of a tipping bucket rain gauge. To measure the inflow to the wetland there was installed an electromagnetic sensor and a data logger apparatus to register the number of intermittent discharges of tipper. Each record represents the discharge of 25 L. The integration of records per hour resulting in the hourly flow (in m^3/h).

To assess the performance of the system, twelve grab samples were manually collected from June 2011 to January 2012 at four control points: raw wastewater (IN), effluent from the septic tank (1° EF) and effluent of each wetland cell (cell-A and cell-B). From January 2012 to July 2012, eight 24-h composite samples were collected proportionally to the primary outflow in three control points: raw wastewater, 1° EF and secondary effluent overall wetland (2° EF). For this, three automatic sampler devices (Sigma 900, Hach, USA) were installed. The automatic sampler apparatus for raw wastewater was scheduled for collecting a grab sample hourly. While the other two devices were programmed to collect a single sample every two hours. At 48 grab samples of each sampling day (24 + 12 + 12) was measured: pH, conductivity and turbidity. The rest of typical parameters (BOD_5, COD, etc.) were measured only in the composite sample proportional to flow rate. Additionally, from September 2012 to September 2015, nine grab samples were collected in each of the three control points: IN, 1° EF and 2° EF.

Samples were analysed for total and volatile suspended solids (TSS, VSS), pH, faecal coliforms (by membrane filter procedure) and alkalinity as standard methods for examination of water and wastewater (APHA, 1998). The analysis of total and soluble COD (COD, s-COD), total phosphorus (TP), ammonium, nitrite, nitrate and total nitrogen unfiltered and filtered (TN, s-TN) were performed with cuvette test kits Dr. Lange and colorimetric analysis on a Lasa 50 (Lange, Germany). Total and soluble BOD_5 (BOD, s-BOD) were analysed with respirometer OxiTop® (WTW, Germany). Dissolved oxygen (DO) and temperature were measured with a probe LDO™ (Lange, Germany).

2.3. Start up

In May 2011 the construction of the WWTP Dormeá was completed. Each cell of the wetland was planted with common reeds. Plants were spaced evenly in the bed (about one plant per m^2). Because of the tipper device failure during the first month of operation, the primary effluent continuously fed only the cell-A (350 m^2). On June 1, 2011 tipper failure was corrected and the primary effluent began to enter intermittently both wetland cells. However, in the cell that had remained "dry" (cell-B) during the first month