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Short communication

A small-size vertical flow constructed wetland for on-site treatment of household wastewater

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ABSTRACT

The design and performance of a small-scale vertical flow constructed wetland (VFCW) system, for on-site treatment of domestic wastewater, are presented. The system serves a two-story, two-family (8 persons) building, and comprises three treatment stages: two settling tanks in series, a VFCW and a zeolite tank. The treatment performance of the system was monitored on a weekly basis for about forty months. Results show a satisfactory performance with the following mean removal efficiencies: 96.4% for BOD, 94.4% for COD, 90.8% for TKN, 92.8% for ammonia, 61.6% for OP and 69.8% for TP. The zeolite was found to offer additional removal of nitrogen, total phosphorus and organic matter. The zeolite saturation time is estimated.

1. Introduction

Constructed wetland (CW) technology for wastewater treatment is a relatively new technology, characterized by efficiency in pollutant removal, simplicity, and low construction and operation costs (Kadlec and Wallace, 2009; Vymazal et al., 1998). Constructed wetland systems are used in many countries, serving relatively small settlements, i.e., of the order of 1000 person equivalent (p.e.). A small number of full-scale CW systems operate in Greece (Gikas et al., 2007, 2011; Tsihrintzis et al., 2007; Tsihrintzis and Gikas, 2010). Several studies were completed showing the effectiveness of CW systems in wastewater treatment under Mediterranean climate conditions (Akratos and Tsihrintzis, 2007; Akratos et al., 2008, 2009a,b; Kotti et al., 2010; Stefanakis and Tsihrintzis, 2012a).

Recent CW applications for domestic wastewater treatment also include the service of isolated houses (4–10 people), mostly located in agricultural and ecologically sensitive regions, or where there is no possibility of house connection to a public wastewater treatment system (Brix et al., 2003; Gikas and Tsihrintzis, 2010; Zakova and Zak, 2003). Such systems are usually of the horizontal subsurface flow (HSF) or vertical flow (VF) CW type, varying in surface areas from 3 to 6 m^2/p.e. and planted with *Phragmites australis* (Brix and Arias, 2005). Usually, two or three settling tanks are placed before the CW for pretreatment of influent (Börner et al., 1998; Vymazal, 2001; Zakova and Zak, 2003).

This paper describes the design and construction details of the on-site wastewater treatment system for a two-family house in Avdira, Xanthi, Northeast Greece, and presents performance results from its 40-month monitoring under Mediterranean climate conditions.

2. Materials and methods

2.1. Facility description

The on-site CW was built to treat the sewage from a two-family residence of 8 people in Avdira, a village in Xanthi district, Northeast Greece (40°58′49.6′′N, 24°56′52.8′′E; Elevation 74 m). This system consists of two settling tanks in series (ST1 and ST2), a vault with a pump (ST3), a vertical flow CW, a zeolite tank (ZT), and an effluent collection tank (Fig. 1). From the residence, the wastewater inflows to the first settling tank (ST1), which overflows to the second one (ST2) and then to the pump vault (ST3). The dimensions of ST1 and ST2 are 1.3 m by 1.3 m in plan view. The operation depth is 1.5 m. The dimensions of ST3 are 0.7 m by 0.7 m in plan view. The operation depth is 1.5 m (Fig. 1). In the vault (ST3), a pump is used to discharge approximately every 3 h 150 L of wastewater onto the

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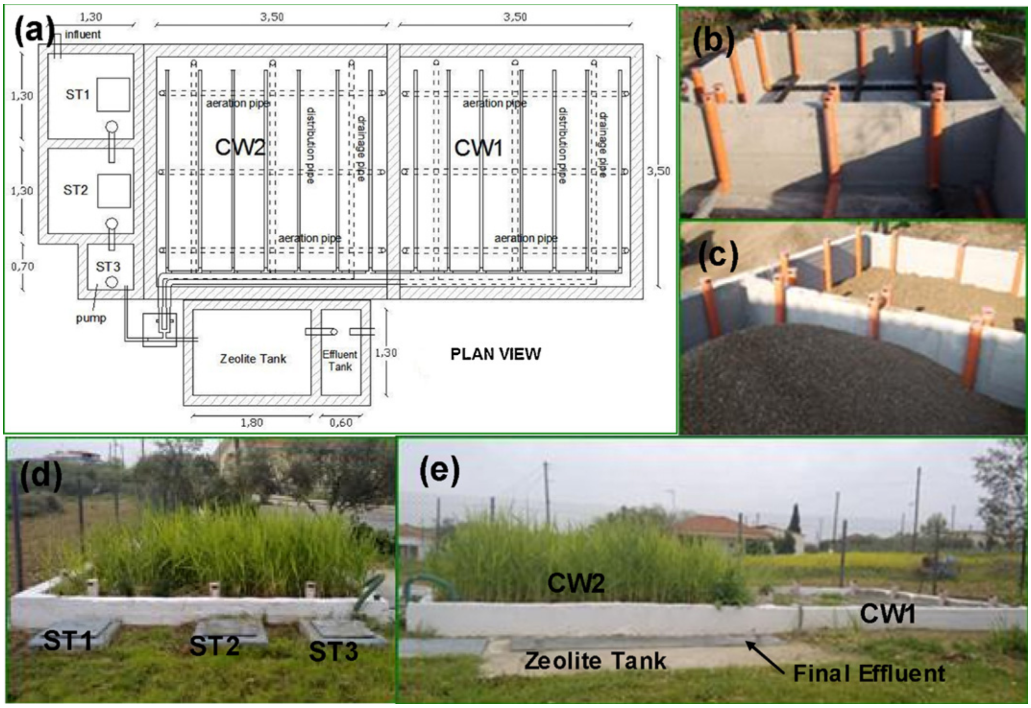

Fig. 1. Constructed wetland system in Avdira, Xanthi district: (a) plan view; (b) aeration pipes; (c) porous media; (d) septic tanks; and (e) constructed wetland cells and zeolite tank.

CW bed. The hydraulic residence time in the two septic tanks is about 4.5 days.

The constructed wetland is of vertical subsurface flow type (area 24.5 m^2). The bed is made of reinforced concrete with vertical walls and is separated in two equally sized cells CW1 and CW2. The dimensions of CW1 and CW2 are 3.5 m by 3.5 m each in plan view, and 1.3 m in depth (Fig. 1). The first cell (CW1) was retained unplanted (for experimental reasons) and the second one (CW2) was planted with common reed (*Phragmites australis*). The CW contains porous media obtained from a river bed and placed in two layers. The bottom layer is 30 cm thick well-washed coarse gravel (D_{50} = 25 mm; range 20–40 mm). A layer of 70 cm fine gravel (D_{50} = 6 mm; range 2–10 mm) was placed on top of the coarse gravel layer. The CW contains networks of drainage and aeration pipes (Fig. 1). The two beds CW1 and CW2 operate simultaneously, without a resting period, and the total influent volume of 150 L is divided in two equal parts of about 75 L in each CW bed.

The effluent from the bed is guided into the zeolite tank for further removal of ammonia and phosphorus. The dimensions of the zeolite tank are 1.8 m by 1.3 m in plan view, and 1.0 m in depth (Fig. 1). The hydraulic residence time in the zeolite tank is about 1 day. After passing the zeolite tank, the treated wastewater enters the effluent tank where it is temporarily stored and pumped for irrigation.

2.2. Wastewater quality monitoring – statistical analyses

The CW was put in operation in January 2007. Its treatment performance was evaluated in 82 sampling campaigns, which took place in the 40-month period from January 2007 until May 2010. Wastewater samples were collected at various locations along the facility, i.e., at the influent and the effluent points of the facility, and at various intermediate points. More specifically: one sample from each settling tank and the pump vault (ST1–ST3), two from each wetland cell effluent (CW1 and CW2), one from the inlet of the zeolite tank and one from the effluent of the facility (Fig. 1). Collected wastewater samples were properly stored in a cool box, transported to the laboratory and analyzed immediately for BOD, COD, TKN, ammonia nitrogen (NH_4-N), nitrate (NO_3-N) and nitrite nitrogen (NO_2-N), ortho-phosphates (OP) and total phosphorus (TP), following standard methods (APHA, 1998). In addition, temperature (*T*), electrical conductivity (EC), pH and dissolved oxygen (DO) were measured in situ, using appropriate equipment (WTW 197-series), at the same points where water samples were collected.

SPSS 15.0 for Windows was used in performing statistical analyses, which included: (1) one-way between groups ANOVA and the Tukey honestly significant difference (HSD) test, to determine statistically significant differences at 95% confidence interval ($p < 0.05$) between the various treatment stages (i.e., influence of stage) of the mean values of pollutant removals; and (2) the *t*-test, to determine statistically significant differences between the mean values of pollutant removals at temperatures above and below 15 °C, and also between the planted and unplanted CW cells.

3. Results and discussion

3.1. Mean physicochemical parameter variation

Measured physicochemical parameters and pollutant concentration statistics are presented in Tables 1 and 2, respectively. Figs. SM-1 and SM-2 [see Supplemental Online Material (SM)] present the seasonal variation charts of these parameters. The wastewater temperature did not show any significant spatial variations along the unit, and generally ranged between 8.5 °C and 31.3 °C, depending on the season (Table 1; Fig. SM-1a). Practically, temperature variation along the facility was minor. Since the wastewater was of domestic origin, the mean pH value was in the neutral area (Kadlec and Wallace, 2009) at every point of the facility, ranging between 7.4 and 7.7 (Table 1; Fig. SM-1b). Mean DO concentrations increased along the facility, ranging from the inlet to the outlet from 0.16 mg/L to 1.21 mg/L (Table 1; Fig. SM-1c). This