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Constructed wetland with a polyculture of ornamental plants for wastewater treatment at a rural tourism facility

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ABSTRACT

Sewage management in remote rural and mountain areas constitutes a challenge because of the lack of adequate infrastructure and economic capability. Tourism facilities, in particular, possess a special challenge because of huge variability in sewage production and composition as a consequence of variations in number of guests and their activities. Constructed wetlands (CWs) are recognized as a robust and economical ecotechnology capable of meeting these challenges.

A horizontal subsurface flow CW system was established at a guest house located in a rural and mountain area of Portugal. The substrate of the bed was an expanded clay substrate, and the system was planted with a polyculture of ornamental flowering plants (*Canna flaccida*,*Zantedeschia aethiopica*, *Canna indica*, *Agapanthus africanus* and *Watsonia borbonica*). The load and composition of sewage varied significantly seasonally (17–579 kg COD ha^{-1} d^{-1}), but removal efficiencies of BOD and COD were generally high (>90%) and independent of the loading conditions. The system also reduced PO_4^{3-} (up to 92%), NH_4^+ (up to 84%) and total coliform bacteria (up to 99%). The ornamental polyculture provided an aesthetic pleasing system with different appearance during the seasons. Of the five species tested, four grew well (*C. flaccida*, *C. indica*, *Z. aethiopica* and *W. borbonica*), whereas *A. africanus* was outcompeted. The system owner cut flowers from the CW system and used them for decorations at the guest house. It was demonstrated that CW systems planted with a polyculture of ornamental plant species, besides the water treatment function, possess several additional benefits including aesthetics and biodiversity enhancement.

1. Introduction

Constructed wetlands (CWs) have been suggested to be an attractive solution for wastewater treatment in geographical remote areas which often lack a sewage network or a centralized wastewater collection system, and where financial resources are scarce (Coleman et al., 2001; Karathanasis et al., 2003; Regelsberger et al., 2005). Remotely located tourism facilities possess additional challenges concerning wastewater management since they may deal with a great variation in wastewater quantity and quality over the year as a consequence of seasonal variation in tourist occupation. Often the current wastewater management systems for such facilities are simple septic tanks. However, these provide very limited treatment and also do not tolerate large variations in loading rate. In addition to being a robust wastewater treatment system, CWs contain wetland vegetation that plays an important role for the removal of several pollutants (Brix, 1997). Large robust wetland species like *Phragmites* sp., *Typha* sp. and *Schoenoplectus* sp. are amongst the most commonly used plant species in these systems. However, ornamental plants appear as a promising alternative, due to their aesthetic and commercial value, possibility for site integration and other added values related to biodiversity and ecosystem services (e.g., Konnerup et al., 2009, 2011). Ornamental wetland species have been applied in a few cases in tropical settings where the aesthetic appearance is important. Examples are the township of Baan Pru Teau in Thailand, which is planted with *Cannae lilies* (Brix et al., 2007), and the multistage CW system at the tourist island Koh Phi Phi also in Thailand, where *Cannae lilies*, *Heliconia* and other ornamental

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wetland species are used to create a water management park with public use values (Brix et al., 2011).

Most CW systems are established with a monoculture of the plant species chosen. It has, however, been claimed that systems with poly- or mixed-cultures may have a more effective distribution of the root biomass and may provide a habitat for a more diverse microbial population compared to systems with only a single species (Karpiscak et al., 1996; Coleman et al., 2001; Karathanasis et al., 2003; Wu et al., 2012). It has also been reported that co-culture of wetland plants may enhance the release of root exudates which might stimulate the uptake of N and P (Wu et al., 2012). Hence, CWs with a mixture of wetland species may be superior compared to CWs planted with only a single species.

The target of the present study was to assess the potential of using a CW planted with a mixture of ornamental wetland plants for the treatment of wastewater at a tourist facility with large fluctuations in wastewater quantity and quality. The use of ornamental plants provides an added value for the tourist facility, as the CW integrates nicely in the surroundings, and as the flowers produced in the CW system can be cut and used as decoration by the facility owner. The CW studied was established at a guest house in a rural area, and was planted with five species of flowering ornamental plants. The plant development and the system treatment performance during the initial year of operation are reported here.

2. Material and methods

2.1. Constructed wetland implementation

The CW was implemented in Paço de Calheiros, a guest house surrounded by a farm, located in Calheiros – Ponte de Lima, in the North of Portugal (N 41° 48′ 24″, W 08° 34′ 04″) in a rural area dominated by agriculture and forests. The CW was designed to be placed after a previously installed septic tank that acted as the main treatment before the CW was established. Occupation rates at the guest house vary from 6 to a maximum of 40 persons. Earth works were carried out to meet the following design characteristics: surface area of the bed, $A = 40.5\ m^2$ ($13.5\ m \times 3\ m$); effective depth of the substrate, $h = 0.4$ m, with a horizontal subsurface flow regime. Layers of geotextile (GEO RPP/09 AG 300, mass per unit area: $300\ g/m^2$) and a geomembrane (ATARFIL HD, density: $0.946 \pm 0.004\ g/cm^3$) were placed at the bottom and sides of the bed before substrate filling. The substrate material used in the CW was Leca®M with a particle size ranging from 4 to 12.5 mm (Saint-Gobain Weber Portugal, S.A.). This material was selected based on previous studies (Calheiros et al., 2008a,b, 2014). The water absorption capacity of the substrate (as a percentage of the dry mass) was calculated after immersion in water for 24 h (WA_{24}) according to the European Standard – EN 1097-6:2000 – test for mechanical and physical properties of aggregates (Part6). The substrate was analyzed for pH, conductivity and porosity (through the measurements of bulk density and particle density), as previously described (Calheiros et al., 2008a,b,b). At the inlet and outlet of the CW a layer of coarse rock was placed in order to facilitate the distribution and collection of the effluent. Feeding of wastewater was made through a perforated polyvinylchloride (PVC) rigid pipe.

The CW was filled with water coming from a fountain before the wastewater was connected to the system. The first month was considered an acclimation period for the plants to the effluent, after which the system was operated for 12 months in continuous mode with regular monitoring of water quality (in general bi-weekly). The system was inspected on a weekly basis to secure stable operation.

2.2. Ornamental plants

The plant material used in the CW was chosen based on three criteria: (i) presence at the site and occurrence in the natural environment surrounding it, (ii) ornamental value to the guest house, and (iii) diversity in species in order to promote biodiversity. Hence, specimens of *Canna flaccida* (63 plants), *Zantedeschia aethiopica* (36 plants), *Canna indica* (33 plants) and *Agapanthus africanus* (33 plants) were transplanted to the CW and cut to a height of 8 cm. Rows (perpendicular to the inlet) of each species were planted starting from the inlet: Z. *aethiopica*, *A. africanus, C. indica* and *C. flaccida*. *Watsonia borbonica* (60 plants) was planted solely at the CW borders. The plants were planted by hand at a density of $4/m^2$. They were visually inspected on a weekly basis for signs of toxicity, such as chlorosis, necrosis and malformation. The CW was divided into six zones, zone 1 at the inlet and zone 6 at the outlet, each split in three compartments, in which marked plant specimens were monitored for shoot height (starting from the substrate level) at least monthly. In the first 3 months the shoot density, in terms of number of plants per species, and flowering, were registered.

2.3. Wastewater sampling and analysis

Wastewater grab samples were collected bimonthly for physico-chemical analysis and microbial counts. Samples from the inlet and outlet of the CW were analyzed based on Standard Methods (APHA, 1998): chemical oxygen demand (COD; Closed Reflux, Titrimetric Method), biochemical oxygen demand (BOD_5; 5-day BOD test), total suspended solids (TSS), pH and conductivity. The analysis of nitrogen and phosphorus were carried out using colorimetric methods: the Griess reaction method for nitrite and nitrate determination (with nitrate reduction); the titrimetric method with bromothymol blue for the determination of ammonium; and the molybdenum blue method for phosphate analysis. The methods were employed in sequential injection analysis (Mesquita and Rangel, 2009).

Water temperature, pH and conductivity were monitored on-site with a WTW handheld multiparameter instrument 340i at the inlet and outlet of the CW. Air temperature and humidity at the time of the sampling were registered. The hydraulic flow was measured manually every time that a sampling trial took place. The number of colony forming units (CFUs) in the wastewater at the inlet and outlet of the CW were determined based on the surface-plate counting procedure using nutrient agar (LABM, UK). *Escherichia coli* and total coliforms were enumerated by plate counting using ChromoCult® Coliform Agar (Merck) and fecal coliforms were enumerated using DIFCO™ m FC Agar.

In order to assess the removal along the length of the CW, eight sampling points (four at the right (R) side of the CW and four at the left (L) side of the CW) were set and water samples were taken 15 cm below the substrate surface and 20 cm from the CW side, with a sterilized glass pipette, in four different months. The samples were taken at 2.5 m (1L and 1R), 5.0 m (2L and 2R), 9.0 m (3L and 3R) and 11.5 m (4L and 4R) from the inlet. The water samples were analyzed for COD, pH and EC.

2.4. Data analysis

Statistical analyses were performed using the SPSS software (IBM Corp., Released 2012. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.). The Student's *t*-test was applied to compare COD, pH and EC at the CW inlet and outlet, and to compare the height of each plant species at the inlet and outlet zones. COD and pH data were analyzed using one-way analysis of variance (ANOVA) to compare the differences between selected