Performance of a pilot-scale wall cascade constructed wetland treating kitchen greywater

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Abstract: A growing water exploitation in urban areas is forcing scientists and policy makers to find alternative solutions for freshwater management. In this context, greywater recycling after treatment is becoming an alternative way for meeting water supply demand. Here, we tested the depuration performance of an innovative wall cascade constructed wetland (WCCW) system that aims to combine the multifunctional benefits of green walls (e.g. aesthetic, low horizontal space demand) with those of constructed wetland systems (e.g. water depuration, water recycling). First results showed that the WCCW significantly reduced the main kitchen greywater pollutants (e.g. COD, MBAS), suggesting its potential application as a water saving and depuration system.

Keywords: Constructed wetland; Kitchen greywater; Nature-based solutions.

INTRODUCTION

The increase of global urban population is coupled with growing demand and use of water, in turn raising the dual problem of freshwater supply and wastewater management. Greywater recycling is being increasingly used as an alternative to freshwater availability because it is a considerable part (up to 80%/v) of total household wastewater (Friedler and Hadari, 2006), with potential water savings that can be more than 40% (Boyjoo et al., 2013). Constructed wetlands (CWs) are nature-based solutions that have been largely used for greywater treatments since they are able of combining several water treatment processes (e.g. physical, microbiological) with multiple ecosystem services (e.g., temperature control, moderation of extreme events, etc.) (Bertule et al., 2014). So far, in tight urban areas a widespread application of CWs was hindered by high space demand. In this context, designing of CWs on green walls, where vegetation is grown on vertical structures, may be a solution. However, there is currently little research focusing on the performance of constructed wetlands for greywater treatments in vertical wall systems (e.g., Fowdar et al., 2017).

With the aim of extending constructed wetland technology to green walls, here we tested: i. the performance of an innovative wall cascade constructed wetland (WCCW) to treat kitchen greywater; ii. the effects of different plant species on the depuration processes.

MATERIAL AND METHODS

The WCCW was set up in June 2017 in the campus "Agripolis" of the University of Padova (Legnaro, northeastern Italy). It consisted of a terraced system (2.13 m high) and six phytoremediation lines, with a total surface area of 16.44 m^2. Each line was composed of three plastic tanks (0.06 m^3) that were filled with lightweight clay aggregates (porosity = 0. 55 m^3 m^{-3}) and vegetated with different plant species in two replicates: *Mentha aquatica* L., *Oenanthe javanica* (Blume) DC., and a mixture of

Lysimachia punctata L. and *Lysimachia nummularia* L. (Figure 1). Plant species were selected for their adaptability to saturated conditions, tolerance to polluted conditions, size and aesthetic purposes.

Greywater used in the experiment came form the kitchen sinks of the canteen of the University of Padova, that is used daily by the staff and the students. A total greywater volume of 90 m^3 is produced yearly and only subjected to a primary treatment in a septic tank and grease trap. The WCCW operated as a vertical flow system, with alternation of saturated-unsaturated conditions as consequence of an intermittent inlet flow that was done daily (7.14 l d^{-1} each line). Based on the communicating vessels, the inlet greywater forced the wastewater already inside the tank to flow vertically through the medium, then to rise along a connecting pipe and to fall in the tank below (Figure 1). Between two feeding cycles, evapotranspiration decreased the water level, determining aerobic conditions inside the tank. The inlet and outlet effluent of every tank (3 × line) was daily monitored during June-August 2017 for physical-chemical parameters (pH, EC, etc.). Inlet and outlet water was also collected for chemical analyses (BOD_5, COD, nutrients etc.).

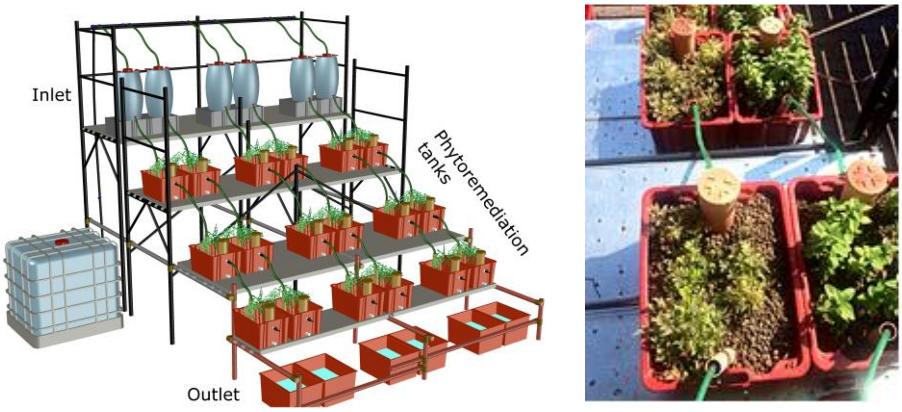

Figure 1 Pilot scale wall constructed wetland system for greywater depuration. Rendering of WCCW design (left) and focus on a vegetated tanks (right).

RESULTS AND DISCUSSION

Inlet greywater was generally characterized by anoxic conditions (dissolved oxygen < 2%) and moderate-low salinity (median EC = 1048.50 µS cm^{-1}), whereas total organic compounds reached maximum values of 2375 mg COD l^{-1} and 700 mg BOD_5 l^{-1}, although characterized by high variability (median = 637 and 200 mg l^{-1} of COD and BOD_5, respectively). The process of phytoremediation along the lines that simulated a cascade green wall system reported significant differences between inlet and outlet in as a result of the strong abatement in suspended solids (i.e. turbidity) and in organic compounds (Table 1). Ammonia was also decreasing after treatments, although with no significant differences. Slight increases of nitrate were observed in the outlet water, which was likely due to an oxidation process (i.e. nitrification) that was not followed by sufficient denitrification conditions. Nevertheless, $N\text{-}NO_3$ was always lower than 1.6 mg l^{-1}. First results from the pilot scale WCCW were promising because the system was able to remove the main pollutants despite the little space available. Only minor differences were observed between lines that compared different vegetation species. This was likely due to a reduced vegetation growth (both aboveground and below ground). It is expected that different plant developments will highlight the strategic role of vegetation in creating best ecologic conditions for water purification.

Table 1 Inlet and outlet median parameters ± standard errors of kitchen greywater as a result of phytoremediation treatment in the WCCW system. Parameters in the row labelled with different letters are significantly different at P<0.05.

	Inlet		Outlet					
			Mentha		Oenanthe		Lysimachia	
pH	8.32[b]	±0.00	8.25[b]	±0.02	8.62[a]	±0.01	8.70[a]	±0.01
EC (µS cm^{-1})	1048.50	±1.22	1438.75	±16.16	1169.75	±3.40	1060.25	±2.10
DO (%)	1.30[b]	±0.03	49.40[a]	±0.87	63.55[a]	±1.10	84.65[a]	±1.18
Turbidity (NTU)	163.00[a]	±75.32	8.73[b]	±0.88	14.35[b]	±0.55	15.65[b]	±0.41
BOD_5 (mg l^{-1})	200.00[a]	±51.18	32.50[ab]	±1.35	30.00[b]	±1.25	30.00[b]	±1.18
COD (mg l^{-1})	637.00[a]	±174.64	72.05[b]	±1.03	73.55[b]	±1.54	67.00[b]	±1.41
MBAS (mg l^{-1})	7.26[a]	±1.36	2.24[b]	±0.12	2.89[b]	±0.10	30.00[b]	±1.18
N_{tot} (mg l^{-1})	46.25	±26.10	20.59	±2.84	25.37	±2.42	16.93	±1.43
N-NH_4 (mg l^{-1})	0.77	±0.04	0.32	±0.03	0.36	±0.02	0.36	±0.04
N-NO_3 (mg l^{-1})	0.04	±0.01	0.20	±0.04	0.50	±0.09	0.34	±0.10
P-PO_4 (mg l^{-1})	12.19[b]	±1.65	31.15[a]	±0.80	24.34[ab]	±0.92	24.30[ab]	±1.13

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