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Original
Investigating green walls for greywater treatment and visualising enzymatic activity in constructed wetlands / Costamagna, Elisa. - (2022 Oct 19), pp. 1-117.

Availability:
This version is available at: 11583/2972556 since: 2022-10-24T11:27:09Z

Publisher:
Politecnico di Torino

Published
DOI:

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29 November 2022

Investigating green walls for greywater treatment and visualising enzymatic activity in constructed wetlands

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Abstract

The European Research and Innovation Policy Agenda points Nature-Based Solutions (NBS) as key technologies to improve the sustainability of urban areas. NBS provide multiple benefits and ecosystem services, developing city resilience against climate change and improving water management, e.g., through increased stormwater retention and infiltration and through wastewater treatment. Green walls are an important type of NBS, recently studied for several applications such as thermal regulation and biodiversity preservation. The main limit of this technology is its water requirement for irrigation. However, wastewater could support the water and nutrient requirements of green walls, hence favouring the circular economy approach. The portion of wastewater that better fits the green wall irrigation and treatment purposes is greywater (GW), i.e. the portion of household wastewater that excludes toilet flushes and kitchen sinks, because it requires only mild treatment and it is available in high quantity. However, multiple challenges hinder the design of green walls for GW treatment, including the choice of the composition of the filter material, the contribution of the number of levels to treatment performance, and the influence of system operational time on GW treatment.

This thesis presents a green wall modular design tested along three years to evaluate the impact of design variation on GW treatment. The system is composed by modular panels with 12 planted pots each. The pots are organised in four columns that are fed separately with high HLR (around 740 $Lm^{-2}day^{-1}$) with water flowing vertically by gravity to the lower pots. Experiments have been performed in four phases, each one characterised by specific objectives, measuring the main physical-chemical and biological parameter from input and output water samples.

The first phase (December 2018-March 2019) aimed to evaluate the effects of different filter media compositions on treatment performances. Preliminary tests were performed to select the plant species and the main filter medium composition. Four additives (compost, biochar, polyacrylate and granular activated carbon) were mixed with the base medium (BM), comparing 8 configurations. Possible compound release form BM was also evaluated testing a configuration fed with tap water. Removal performances were satisfactory for many parameters for most of the tested configurations. Compared to the base medium, biochar was the best performing additive over the highest number of parameters, compost also achieved high removal performances, but the frequent clogging events occurred during the monitoring period do not make its use recommendable. Granular activated carbon and the combination of biochar and polyacrylate performed better than the base medium, but only for the removal of nitric nitrogen. The outcome of phase 1 led to the choice of configurations for the second phase.

The second phase (April-June 2019) tested the possible improvement of the best configuration arisen from the previous phase by adding graphene, which is a material with high potential for contaminant removal. Moreover, the possible influence of different system ages was verified comparing an older and a newer set of the best configuration of phase 1. Water samples were also collected along different levels of the green wall, to quantify the contribute of each level to the overall treatment performance and to obtain preliminary indications for the design geometry of the green wall. Results showed that the addition of graphene did not significantly improve treatment performance, that GW was mostly treated by the first two levels of the green wall, and that treatment performances slightly decreased after three months of operational time.

The third phase (January-March 2021) aimed to evaluate the impact of operational time on the system comparing two identical modules at two-year-distance as set up time difference. Water samples were collected along different levels of the green wall to better understand the contribution of each level of the module. Both panels exhibited very good removal efficiencies for TSS, BOD_5, COD, TN, MBAS. The newer panel reached satisfying pollutants removal after two levels, while the older one showed higher variability and clogging phenomena. This highlighted that the third level was necessary to guarantee good performances after over 2 years of operation for the chosen configuration.

The fourth phase (April-December 2021) consisted in stress tests aimed to test system resilience to feeding flow rate variations. The green wall design slightly changed in drainage system and filter medium composition, due to the lessons learnt during previous phases (e.g. due reduce the risk of clogging and waterlogging). The treatment performances increased along the columns in both panels, and the first two levels guaranteed a good removal during standard flow and underflow rates. On the other hand, the overflow rate caused a performance decrease for many parameters, followed by a visible plant stress. However, after one week of reverting to standard flow rate reduced the negative effects on plants of the three-weeks-overflow period.

Finally, the second part of this thesis focuses on a non-invasive methodology that allows a deeper comprehension of the microbial activities within a porous medium in CWs at mesocosm scale. This innovative photographical method was proposed by Dr. Gagnon and Dr. Chazarenc in 2014 and it is based on the use of fluorescein diacetate (FDA) and its response to UV-light after bacterial metabolic processes. During this thesis, the picture processing procedure has been optimised and automatized to visualise the enzymatic activity in 2D maps over time for three mesocosms planted with different vegetation species.