Green walls as hybrid water reuse systems

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Highlights

- Pollution uptake limits of novel stormwater-greywater treating hybrid green walls
- Stable hydraulic performance (no clogging) and high pollutant uptake across varied conditions
- Plant species choice is critical for robustness of the system (anti-clogging and anti-leaching)

Introduction

Water scarcity and climate change are forcing us to design smart systems for integrated urban water management, that work under varied conditions, preforming as water retention and treatment systems during wet periods, but also be highly resilient to drought during prolonged dry periods. Vegetated, nature-based solutions are perfect for adaptation to these needs, due to natures resilience and flexibility to overcome even the toughest weather conditions. However, densely built urban environments are the most vulnerable to these extreme weather patterns, and most nature-based systems, such as tree-pits, wetlands and rain gardens cannot be built in such a confined space, so novel solutions are required.

Green walls (vertical gardens) present perfect solutions. They are vertical systems, with no horizontal footprint and offer the highest amenity of all nature-based systems, with additional benefits such as cooling, energy reduction, noise and air pollution reduction, economic and social benefits (Perini and Rosasco, 2013). Similar to green roofs, green walls can be used for stormwater retention and treatment during wet weather events, but, due to their position on the wall, can be also cost-effectively utilised during dry weather for household greywater treatment, negating any potable water needs. Coupled with smart monitoring technology, this could be highly reliable on-site, decentralised urban water management and reuse system (Riley, 2017). The need for these hybrid stormwater-greywater green wall treatment systems has been recently highlighted by Pradhan et al. (2018), but full design has not been proposed yet.

While designing hybrid green walls is the primary objective of this project, before testing the combination of stormwater and greywater inflow, green wall system needs to be optimised to successfully treat higher pollution contributor, greywater. Hence, this work will focus mostly on understanding pollutant removal performance of different components of green walls irrigated by domestic greywater as a first step towards hybrid on-site water treatment system. Optimal green wall soil, plants and operational conditions are tested and discussed, with the comparison of effluent water quality against reuse guidelines.

Methodology

To optimise green wall design, synthetic greywater mix was prepared and used throughout the experimental process, with the target concentrations: TSS = 100 mg/L, TN = 6 mg/L, TP = 3 mg/L, COD = 250 mg/L and *E. coli* = 3×10^3 MPN/100mL. Two independent studies were conducted: (1) optimising soil choice for pollution treatment and hydraulic performance, and (2) using long-term green wall experiment to test plant species pollutant removal and how operational factors impacting system robustness.

Soil testing

Unvegetated column study was designed to test a range of potentially suitable media: (1) hydraulically slow coir, rockwool and fyto-foam, and (2) hydraulically fast perlite, vermiculite, growstone, expended clay and river sand. The test was conducted over two months with accelerated greywater dosing, to stress the systems. In depth pollutant removal analysis was undertaken on top two soil candidates, followed by additional unvegetated column study to understand optimal ratio of these media types (six ratios tested). All the tests have been performed in controlled environment with appropriate replication of the samples.

Plant and green wall operation testing

This experiment used commercial *Gro-wall® 4* green wall systems (Atlantis, Australia), with three vertical pots used as one testing configuration (approximately 600 mm soil depth). Each configuration had a same plant species and total of 13 different ornamental plant species were compared in this study, including *C. appressa, N. domestica, A. majus, O. japonicus, A. praecox, N. obliterate, V. tricolor, L. muscari, P. occidentalis, N. officinale, M. parvifolium, D. tasmanica* and *P. tenax*. These were compared against unvegetated configuration. Green wall was watered by greywater drip irrigation with 8 L/h, equivalent to 30 L/m^2 for entire green wall. The experiment was running for one year with ten water quality sampling campaigns assessing inflow and outflow for TSS, TN, TP, COD and *E. coli*. In addition to comparing performance of different plants, experiment tested how change in hydraulic loading rate, drying periods and concentration spikes in the inflow affected green wall pollutant removal performance.

Results and discussion

Soil selection

Through testing hydraulic performance, it was seen that infiltration rates of Fast media types (perlite, vermiculate, sand, etc.) did not vary significantly from the initial average rate of 700 mm/h (which was restricted flow rate), however, Slow media (coir, foam and rockwool) experienced significant clogging and a rapid decline to 100 mm/h, and some had to be discontinued from further experiment due to total clogging. Hence, it was observed that slow media only cannot be effectively used in the green wall, especially due to high TSS contribution of the future stormwater application. Slow media showed higher and more consistent pollutant removal performance than Fast media, averaging around 90%, 50%, 30%, 70% and 80% removal of TSS, TN, TP, COD *E. coli*, respectively, compared to 80%, 30%, 15%, 30% and 20% of Fast media. Hence, the combination of best performing Fast and Slow media, perlite and coco coir, was proposed and adequate ratio tested. Testing six perlite and coir combinations pointed that 1:2 perlite to coir ratio shows the best hydraulic and pollutant removal characteristics if slower irrigation is used (up to 10 L/h per green wall pot), while 3:1 perlite:coir should be used for buffering heavier water loading. For the purpose of greywater 1:2 ratio is used, while for hybrid systems higher ratio of perlite prevent clogging.

Plant and operational performance assessment

The overall green wall pollution removal results showed effective removal of most pollutants across green wall designs (**Figure 1**), with average TSS, TN, TP, COD and *E. coli* removal of 98%, 87%, 29%, 93%, and 87%, respectively. While slight variation across different plant species is seen throughout standard operation conditions, after challenging the system with 2-week drying, beneficial role of plants in TN uptake can be seen, with higher performing plants like *C. appressa, N. obliterate, L. muscari* retaining their high nutrient uptake, while some configuration leached (**Figure 2**). This was attributed to high NO_x uptake. While plants played a significant role in TP removal, overall performance was low, due to short retention times (30 minutes) and non-presence of saturated zone, which was found beneficial in stormwater rain gardens. However, phosphorus uptake improved over time, suggesting that plant growth is significant TP removal mechanism in green walls.

Sudden inflow concentration boosts (double the normal) and change in hydraulic loading rates (lowering and increasing HLR) did not have significant impact on green walls performance, suggesting high robustness and adaptation of the system to operational factor change (**Figure 2**). However, after drying system experienced performance drop, showing system stress and change in microbial structure within the green wall. Nevertheless, this change was temporary, and system was able to quickly recover.

Overall, green wall produced high quality effluent, which satisfied EPA guidelines for unrestricted public use, toilet flushing and cold-water supply across TSS, BOD, EC and turbidity. The only pollutant that was higher than standard was *E. coli*, which is typical for passive vegetated filtration systems (Chandrasena et al., 2014) and usually requires additional post-treatment, such as UV disinfection.

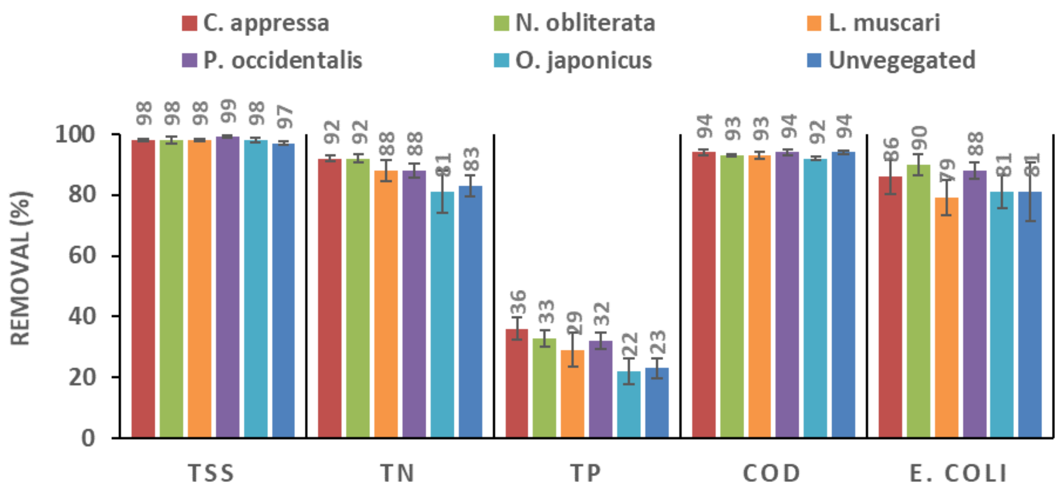

Figure 1. Pollutant removal performance of five different plant species and unvegetated design after one year

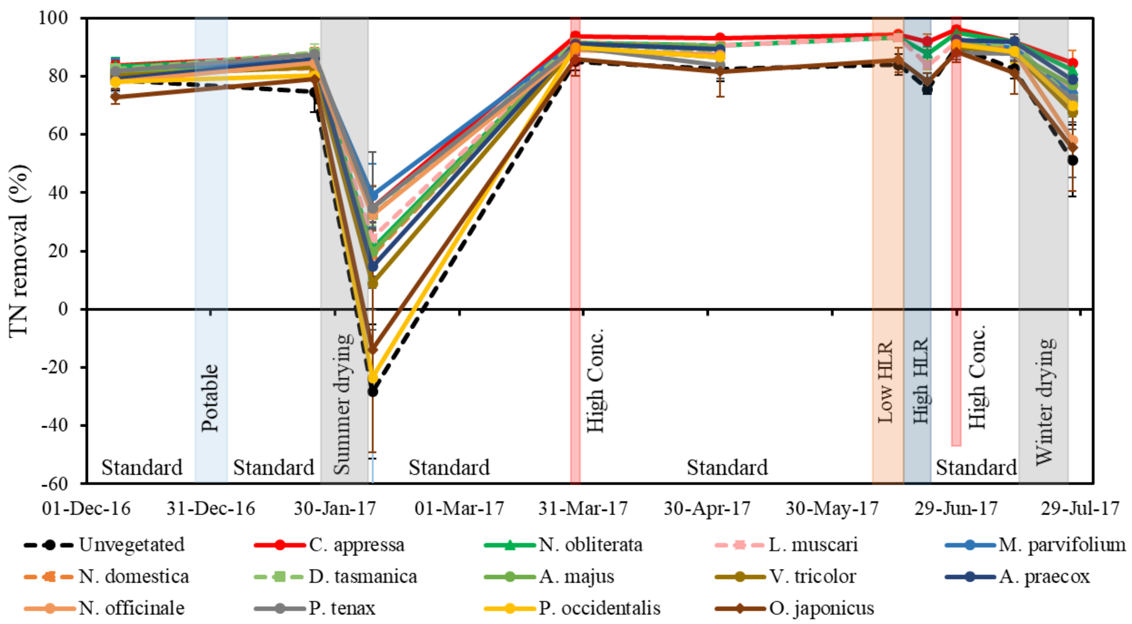

Figure 2. TN removal across all tested plant species and different operational conditions

Conclusions and future work

Based on the results, it can be concluded that green wall medium plays a major role in greywater treatment, and that it should be carefully selected to suit specific design conditions. If inappropriate medium is chosen, it can lead to nutrient leaching and systems inability to achieve required level of treatment. In addition, inclusion of highly effective plant species can significantly boost systems resilience to unexpected operational changes, while maintaining high nutrient uptake. These studies gave efficient preliminary design, which will be implemented in the next experimental stage when full hybrid system will be tested, changing stormwater and greywater application to simulate field conditions.

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