Vertical Gardens for greywater treatment and recycling in dense urban areas: a case-study in Pune

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Abstract: the NaWaTech project aims to use natural extensive treatment technologies in densely populated urban areas in India. The implemented sanitation systems shall facilitate resource recovery and reuse. The paper describes a pilot installation of a vertical garden treating greywater from an office building in Pune, Maharashtra State. The pilot installation is located at the main entrance of the state agency responsible for water supply and sanitation. The experimental analysis has been divided in two phases. First phase has analysed the results from green walls filled only with LECA. Since results from the first phase have not been enough satisfactory, a second phase has been developed. In the second phase, LECA plus sand and LECA plus coconut fibres are tested as porous media, in order to increase residence times and consequently green wall treatment performance. The expected improvements in treatment efficiency have been confirmed by the wider range of observed removal rates between Phase I (COD 16–20%) and Phase II (i.e. COD removal in the order of 14–86% and 7–71% for LECA-coconut and LECA-sand, respectively), denoting higher treatment potentialities for the new configurations. The obtained effluent quality was fulfilling the Indian law specifications for reuse in irrigation for all the analysed samples, while only the last samples collected during Phase II were showing an appropriate quality for reuse by flushing toilets.

Keywords: greywater reuse; green walls; vertical gardens

Introduction

Adequate water supply in terms of quality and quantity has always been a challenging task for developing cities across the world. The scenario is not different in India where rapid urbanisation and population growth has increased the stress on water bodies. Across the country there is a strong variation in the water available for users as class 1 cities have average water supply of 80 litres per capita per day (Tamil Nadu) to 540 lpcd (Chandigarh) (CPCB, 2010). This has forced many ULBs to develop laws for compulsory recycling and reuse of wastewater. Economic and energy based analysis on conventional treatment systems clearly indicate the high energy, capital and O&M demand of these systems while the possible energy generation is quite minimal (Svardal and Kroiss, 2011). This is further complicated by the process of building large sewer networks and pumping stations. Hence for a rapidly urbanising Indian city, building and maintaining such systems becomes a challenging task.

Natural wastewater treatment systems have been proven to be cost-effective, efficient and user-friendly in many studies. Technologies such as constructed wetlands, sub-soil filtration and storage and bank filtration, have shown promising capabilities in treatment of domestic and industrial wastewater (e.g., Vymazal 2011; Vymazal, 2014). However these systems have much higher land footprint compared to the conventional system.
Principles of source separation of wastewater classify domestic wastewater into blackwater and greywater. Blackwater comprises of the discharge from kitchen and toilets while greywater is low polluted wastewater from bathtubs, showers, hand washing basins and washing machines (Nolde, 1999). In residential buildings blackwater generation is generally a very low fraction, less than 30% of the total, in non-residential buildings (commercial, offices, etc.) even less (Scheumann et al., 2009; Li et al., 2009). Hence greywater treatment can be used for recycling most of the wastewater generated by a close loop cycle (Dixon et al., 1999).

While many technologies are available for greywater treatment, natural systems like constructed wetlands have shown advantages of low energy requirements together with a simple and cheap maintenance (e.g., Masi et al., 2010; Li et al., 2009). In the project NaWaTech (www.nawatech.net) many such technologies have been evaluated through pilot and full-scale implementations in urban areas of Pune and Nagpur – two class 1 cities in the state of Maharashtra in India. While root zone treatment systems like constructed wetlands for wastewater treatment have shown high potential in rural settlements, the area footprint of these systems has been a bottleneck in mainstreaming them in the urban areas where land value is high.

In this specific study, the potential of green walls have been explored as a viable greywater treatment system that can extremely minimise the treatment footprint and provide a series of benefits in the urban landscape (greening, CO₂ trapping, O₂ production, microclimate effects, houses insulation, etc. – Francis and Lorimer, 2011). If the concept of recycling greywater at building or block level could be applied on large scale in a city, this approach could strongly reduce the dependence by very expensive infrastructures like sewer systems and end-of-pipe large wastewater treatment plants, optimising by an effective decentralised treatment the overall wastewater management and operative conditions for the treatment itself. The urban development strategies planners could therefore make use of different values for the usual pro-capite parameters when designing lighter sewer networks and optimised treatment units, better if focused on the recovery of resources conveyed by the black water fraction.

Material and Methods

The experimental set up was constructed on the front walls of the office of Maharashtra Jeevan Pradhikaran (Water Supply & Sanitation Department of Maharashtra state) situated in Pune. The office houses 125 fixed staff and a daily visitor count of 65 in average. Dual plumbing was installed in the first and second floors of the building which connects approximately 60 staff and 25 visitors connected to a storage tank of 300 L capacity. The pilot green wall comprises of two parallel units on either sides of the entrance. The inflow from the collection tank is stored in two intermittent loading tanks of 100 L capacity each whose outflows are controlled by a timer based solenoid valve. The feeding of the treatment unit happens through a hourly flush of 10 L of greywater. The discharge is directly allowed to flow into the garden next to the walls.
Each individual treatment unit consist of a 12 x 6 matrix of pots (6 pots in a column and 12 pots in a row). Each pot has a top surface of 0.01 m². The pots have been planted of the following genus *Abelia*, *Wedelia Portulaca*, *Alternenthera*, *Duranta*, and *Hemigraphis*. A perforated pipe is used for loading the first row of pots. The water flow is hence divided along the columns of the matrix arrangement and is collected at the bottom by a drain pipe as shown in Figure 2.

The experimental analysis has been divided in two phases. Initially, the pots have been filled with an inert planting material – LECA (light expanded clay aggregates) – to ensure that the only nutrient source for the plants is the greywater. In this first phase, samples of the inlet and outlet have been collected weekly and analysed in terms of organic content (BOD5 and COD). Since results have not been enough satisfactory, this phase was ended (lasting from 12th of February to 27th of April 2015) and a second experimental phase was started (from 30th of April up to now). In the second phase the LECA has been mixed with two different other mediums (sand and coconut fibres) for the two different pilot green wall units. The aim of the second phase is to slow the water flow, increase residence time, and favour a greater biofilm development. Coconut shell has been adopted due to its high local availability in India, and the lower cost and weight compared with sand. During the green wall lifespan, coconut is expected to disappear due to degradation, but slowly enough (high lignin compounds) to allow a full development of plant roots which would guarantee a proper green wall functioning. Samples for the analysis of SS, BOD₅, COD, NH₄⁺-N, TKN, PO₄³⁻, MPN and E.coli have been collected during the second phase. The results of the first phase are hereby reported as well as preliminary results of the second phase.
Results and Discussion

The pilot system has been put in operation at the beginning of February 2015. The greywater produced by the offices building is quite light in terms of concentrations, with BOD$_5$ and COD respectively in the range of 5-47 mg/L and 32-90 mg/L. The average BOD$_5$/COD ratio is equal to 0.47. The low contamination with organic matter compared to typical greywater can be explained by the fact that only greywater from hand washing basins is collected in this particular situation. The usually stronger contaminated greywater fractions, i.e. from kitchens and washing machines, are not present in the MJP office buildings.

Influent and effluent concentrations for the two experimental phases are resumed in Table 1. During the first phase the system has shown a low average organic removal efficiency of 18.3% and 24.6% for COD and BOD$_5$, respectively (Table 2). These results suggest a scarce biofilm development, with removal mainly driven by filtration process only, and a quite fast percolation of the water throughout the LECA layer that does not allow for an appropriate contact time between the solution and the active agents involved in processes like adsorption and biosorption. The top layer in the pots was in the Phase I still completely unclogged and the biofilm was starting to develop. These results could also be explained by a concentration effect created by the evaporation and evapotranspiration of the water from inside the pots; measures of the outlet flows are currently performed for evaluating the % of volume reduction that can be reasonably considered in hot days. The slow biomass growth can also be justified by the very low content of nutrients (C, N, P) in the inlet.
Relating to the second phase, COD, BOD\textsubscript{5}, SS, NH\textsubscript{4}\textsuperscript{+}-N, TKN influent and effluent concentrations are shown in Figure 4. The unit filled with mixed LECA and coconut fibres (Figure 4) has shown a release of Carbon generated by the more biodegradable fraction of the coconuts fibres up to the 19\textsuperscript{th} of June, with alternate higher and lower influent, compared to effluent, concentrations for COD, BOD\textsubscript{5}, SS, NH\textsubscript{4}\textsuperscript{+}-N, and TKN. At the end of this start-up period, a proper biofilm seemed to be developed, even if an increase in COD, BOD\textsubscript{5}, and NH\textsubscript{4}\textsuperscript{+}-N concentrations in the vary last sample could suggest that the release phase is not completely ended yet. Further analysis, which will be carried out in next months, are requested to confirm the end of organic fraction release of coconut fibres and the proper development of the biofilm. As regard the unit filled with LECA and sand, interesting removal efficiencies have been observed for all the parameters studied, with higher performance for COD, BOD\textsubscript{5}, and NH\textsubscript{4}\textsuperscript{+}-N when compared with SS and TKN. Coconut fibres seem to perform better than sand and this aspect can be related to the longer retention time provide by the adoption of this filling material in the pots: a complete fill and drain cycle has a duration of 12 minutes in the LECA-sand unit while instead it goes up to about 40 minutes in the LECA-coconut unit.

| Table 1 Influent and effluent concentrations from the two experimental phases. |
|---------------------------------|-----------------|-----------------|
|                                 | Phase I LECA | Phase II LECA-Coconut | Phase II LECA-Sand |
|                                 | Influent [mg/l] | Effluent [mg/l] | Influent [mg/l] | Effluent [mg/l] | Influent [mg/l] | Effluent [mg/l] |
| COD                             | 84.9±2.5 | 69.4±1.7 | 58.3±16.5 | 48.8±35.1 | 63.9±21.3 | 44.7±22.8 |
| BOD\textsubscript{5}           | 39.7±3.2 | 29.9±2.5 | 21.1±8.2 | 17.4±14.0 | 23.0±10.5 | 14.4±10.3 |
| NH\textsubscript{4}\textsuperscript{+}-N | – | – | 3.6±1.3 | 1.9±2.3 | 3.4±1.2 | 1.0±0.6 |
| TKN                             | – | – | 5.7±1.0 | 7.3±4.2 | 4.9±1.5 | 5.0±4.7 |
| SS                              | – | – | 62.5±24.1 | 47.0±22.8 | 61.2±28.1 | 52.6±22.5 |
| n° samples                      | 14 | 10 | 6 |

The statistical analysis of COD and BOD\textsubscript{5} removal efficiencies for the two different phases is reported in Table 2. This comparison confirms the improvement of the performances driven by the changes adopted in the second phase. Indeed, COD average removal efficiency is increased from 18.3% in the first phase to 60.0% and 30.1% for LECA-coconut and LECA-sand vertical gardens in second phase, respectively. Similar improvements have been registered also for BOD\textsubscript{5} removal. Note that only samples after the end of coconuts organic fraction release (i.e. after the 19\textsuperscript{th} of June) have been used here in the analysis related to LECA-coconut vertical garden.

The improvements are also confirmed by the wider range of observed removal efficiencies of single samples between Phase I (i.e. COD removal of 16–20%) and Phase II (i.e. COD removal in the order of 14–86% and 7–71% for LECA-coconut and LECA-sand, respectively), denoting higher treatment potentialities for the new configurations. Higher and more stable removal efficiencies are expected with the
increase of plants rooting and the growth of the biofilm; this assumption will be checked by the further analysis planned in the next months.

Figure 4 Results from the second experimental phases. Thick black vertical line denotes the supposed end of coconut fibres organic fraction release.
Table 2 COD and BOD₃ removal efficiency statistics for the two experimental phases.

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<thead>
<tr>
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<th>COD removal efficiency</th>
<th>BOD₃ removal efficiency</th>
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<tr>
<td></td>
<td>Phase I</td>
<td>Phase II</td>
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<tr>
<td></td>
<td>LECA [%]</td>
<td>LECA-Coco* [%]</td>
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<td>n° samples</td>
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<td>4</td>
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</table>

* From 19th of June (only after the end of coconut fibres organic fraction release)
** From 9th of June (all samples for LECA-sand vertical garden in Phase II)

The effluent quality was in all samples already suitable for reuse by land irrigation according to the Indian regional and national regulations; in the last samples collected in Phase 2 the effluent reached an appropriate quality for reuse by flushing toilets (considering in the treatment scheme a further disinfection by an UV lamp).

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