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Green-wall based treatment for reclamation of greywater: A new approach

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This paper presents reclamation of greywater using "Green-wall treatment system". A Green-wall of capacity 100 L/d has been implemented with the aim of greywater reclamation from a bathing water facility. The treatment system comprised of a degreasing tank of size 0.9 m x 0.9 m x 0.3 m for oil & grease removal, followed by a Green-wall. Removal of oil & grease has been done along with commonly observed pollutants in greywater, to prevent clogging of filler material. In stage-I studies, Green-wall pots are filled with 4–10 mm Ø inert filler material LECA and in stage-II, LECA is mixed with locally available coconut peat in equal proportion. Stage-I studies using LECA indicated that maximum achievable HRT is 12 h and the treated greywater with respect to BOD does not comply with USEPA (2012) norms for landscape irrigation. In stage-II, the optimized performance is observed at 16 &18 h HRT at hydraulic loading rate 67–70 L/m^2/d, when compared with 14 and 12 h HRT. Treated greywater quality met the prescribed permissible limits with respect to BOD, TSS and FC and is observed to be innocuous in terms of the reuse options for agriculture and landscape irrigation. In stage-II, the BOD, COD, TSS and FC reduce from 48 to 10 mg/L, 58 to 18 mg/L, 96 to 10 mg/L and 400 CFU/ 100 mL to below detectable limits, respectively, at 18 h HRT.

Keywords: Bio-filtration, Coconut peat, Green-wall based treatment, Greywater, LECA, Reclamation, Wastewater treatment

Introduction

Water usage has significantly increased in the past century due to rapid urbanization, population growth and change in living standards in both developed and developing countries. Water scarcity is a major concern currently, which will be further amplified as ever increasing population is putting up stress on dwindling water resources. Climate change and energy demand would further complicate the complex relationship between development & consequent water demand. Almost half of the global population (73% in Asia) is facing water scarcity for at least one month per year, which is likely to increase to 4.8–5.7 billion by 2050[1]. More than one-third of the world populace is affected by water scarcity and this is projected to further worsen in the future, as population and urban areas continue to grow and expand[2,3]. Availability of water to meet the requirements will be one of the utmost important challenges in the coming years owing to increased demand with population rise, economic development and shrinking supplies due to over-exploitation and pollution. Alternate water supply and demand options are being explored and treated sewage (domestic wastewater) has great potential for non-potable reuse. Many a times, sewage treatment systems are energy intensive, require massive and extensive infrastructure, highly skilled manpower and often use chemicals. Greywater is comparatively less polluted as it does not contain black water and can be easily treated. On-site greywater reuses within the urban and semi-urban sectors do have a significant role in reducing the overall water consumption, leading towards more sustainable urban water utilization[4].

Greywater constitutes about 55-75% of total household wastewater and its reuse for non-potable purposes has very high scope[5], as it doesn't have significant faecal coliforms and organic contaminants[6]. The characteristics of greywater vary from place to place according to the activity due to variations in number, age, lifestyle, health status, water usage patterns and choice of household chemicals for washing/laundry. Large variations in greywater quality and quantity with respect to time and source have been reported and it was suggested that the selection of a treatment system largely depends on variability of greywater characteristics and quantity[7].

A wide range of greywater treatment technologies are implemented and they produce effluents of different quality[8] reported greywater treatment through a membrane biofilm reactor (MBfR) and found simultaneous removal of total COD (95%)

and inorganic nitrogen (99%) at 7.68 h hydraulic retention time (HRT). Membrane separations coupled with other technologies are reported to ensure better treated greywater quality and conform to greywater reuse guidelines[9]. Combined electrocoagulation (EC)/ozone process was studied for the treatment of greywater[10].

Nature-based solutions for greywater treatment and reuse such as conventional constructed wetlands and new integrated approaches e.g., green roofs and walls have also been reported recently[11]. They also studied treatment efficiencies as a function of hydraulic operating conditions and suggested threshold values to ensure high removal performance. Reduction in organics and nutrients from greywater through vertically planted ornamental plants in artificial media such as coco coir, spend coffee grounds and sand is also studied by some researchers and it was found that substantial organic matter removal takes place due to microbial activities, whereas plants contribute towards nutrients uptake[12]. Performance of hydroponic green roof system at 4, 6, and 8 days HRT for the removal of organic matter, anionic surfactants and turbidity was observed to be maximum at higher HRTs[13]. Studies on development of pot and block based Green-wall treatment systems for greywater have also been reported in which it was found that organic matter, total suspended solids, *E coli* and nutrient removal were at par with those reported by other researchers under standard operating conditions[14].

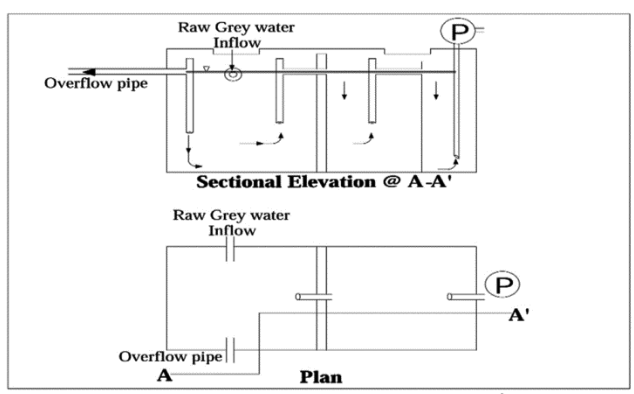
One of the most promising sectors, where substantial quantity of greywater is generated is Public Bathing Water Facilities (swimming pools). Greywater generated from showers/bathing before and after swimming and urinals has very unique characteristics, since it does not contain any other greywater from kitchen and utensil and floor washings. This makes it more amenable for treatment through natural systems like Green-walls. In this study, we analyzed greywater and implemented a treatment technology with the aim of reuse to cope up with horizontal space constraints by using plants and media. A special emphasis is given to oil and grease removal, in addition to conventional pollutants, since the former is usually found in greywater and difficult to remove through biological processes and known to cause process upsets due to clogging. Potential of the Green-wall system also synonymously referred to as “bio-wall” has been explored as a viable greywater treatment system that can greatly diminish the treatment footprint area and provide a series of benefits in the urban landscape such as greenbelt development, temperature control, improved aesthetics and fresh water conservation.

Experimental Section

Materials and Methods: Experimental setup

The experimental setup of capacity 100 L/day was implemented at bathing water facility of CSIR-National Environmental Engineering Research Institute, Nagpur, India. The treatment system comprised of a collection sump with provision for degreasing, followed by a Green-wall. Removal of oil and grease through degreaser was essential to prevent choking of filler media. The degreasing tank as shown schematically in Fig. 1 has effective dimensions of 0.9 m x 0.9 m x 0.3 m and with provision for manual degreasing. Degreasing tank was divided in two chambers, in the first chamber raw greywater was collected and an overflow outlet was provided for excess greywater drainage. For segregation of oil and grease, two L-shape pipes of 90 mm Φ and 150 mm vertical length were provided on each side of the wall that separated two chambers and an opening of size 150 mm was provided in this separating wall at 0.2 m above the bottom to allow greywater to flow from first to second chamber. Greywater was finally pumped from the bottom of second tank. After removing oil and grease from greywater, it was pumped and stored in overhead tank of capacity 150 L, thereafter greywater was fed to Green-wall unit under gravity.

The functioning of Green-wall is based on the principles of vertical flow constructed wetlands that



Degreaser (0.9 X 0.9 X 0.3 m)
(inner dimensions)

Fig. 1 — Schematic diagram of degreasing tank with baffle wall arrangement

offers the advantages compact and low-cost treatment for greywater[15]. Like constructed wetlands, Green-wall also involves multiple processes such physical, chemical, biological and phytoremediation with only difference in the applicability of strength of wastewater characteristics. Prominent among the processes involved in treatment are, filtration & adsorption by media, and biodegradation by microbes and nutrient uptake by plants. The functioning of Green-wall is also affected by operating conditions such as hydraulic loading rate (HLR, L/m^2/d) [15], HRT and formation of bio-film layers in the upper zone[16], depth of filter bed and size[17,18]. In the existing studies Light Weight Expanded Clay Aggregate (LECA) combined with coco peat (coconut husk) was used as a filler media which acts as filtration and adsorption material for TSS and N removal, respectively. The long term use of media results in clogging of upper layer, which also enhances biodegradation and pathogen removal[19]. However, LECA and coco peat (coconut husk) have larger size, hence the probability of clogging is minimized. The P uptake is done by plants and biodegradation is done by bacteria in the plant root zone. The details of experimental set-up are described in the following section.

Green wall unit comprised of pots (450 x 350 mm) of UV resistant plastic material. Filler media used in pots was Light Weight Expanded Clay Aggregate (LECA) combined with coco peat (coconut husk). These pots (54 Nos in three sets of treatment units) were placed in six rows one over the other with provision for feeding water through a pipe system and planted with suitable species that are homogeneous in nature. Locally available plants species viz. *Alternenthera Green, Aletrnenthera Versicolor, Asperagus Sprengeri, Syngonium* and Dwarf *Canna Indica* were selected. The raw greywater was fed through the top most rows, which dripped down to all the rows from top to bottom and treated effluent was collected in a tank. Figures S1 and S2 presented in 'supplementary material' depict the details of the commercially available Green-wall frame, pots and filling material viz. LECA & coco peat, and various plants species used in the existing studies, respectively. The schematic diagram of Green-wall system for stage – I & II experimental set-up is presented in Fig. 2.

The entire study was carried out in two stages, in which two different types of filler media were used whereas the plant species were same in both the stages. Physico-chemical characteristics of raw & treated greywater were assessed for major parameters including pH, total suspended solids (TSS), total dissolved solids (TDS), total kjeldahal nitrogen (TKN), alkalinity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total coliform (TC), faecal coliform (FC) and total phosphate. All these parameters were measured according to the Standard Methods for Examination of Water and Wastewater (APHA, 2005)[20].

Greywater was collected from bathing water facility for 4 h duration during morning and evening separately and fed to Green-wall to study the performance under various operating conditions. Provisions of sampling ports were made at the bottom of the vertical component of each set as shown in experimental setup in Fig. 3 along with drainage pipe. The outlets from all three sets were placed at 80 cm above the ground surface. In stage-I, the pots were filled with 4–10 mm Ø LECA and inlet and outlet samples were collected for performance assessment. In stage-II, the LECA was mixed with locally available coconut peat in equal proportion. The major objective of the second stage was to study the slowdown of greywater flow, increase residence time and favour thicker biofilm development.

Results and Discussion

Initially raw greywater samples were collected at inlet during the morning and evening hours at bathing water facility to assess variations in characteristics. Table 1 presents variations in greywater characteristics under existing conditions and those already reported elsewhere in literature[21]. A comparison between greywater recycling by PUB National Water Agency Singapore and existing actual values with respect to TSS, BOD and conductivity indicated significant variation in characteristics of greywater. However, the maximum values for pH,

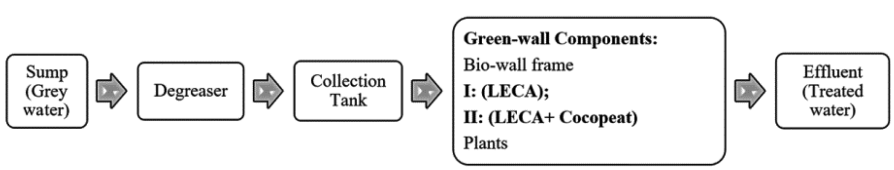


Fig. 2 — Schematic diagram of treatment system; Stage – I & II

TSS and phosphate were similar. Total coliforms and faecal coliforms for various greywater sources and existing greywater samples were also found to vary in sources of greywater as shown in Table 2. This indicated that greywater characteristics are site specific and it is utmost necessary to examine its characteristics prior to designing any Green-wall system. For the existing case, average actual design values mentioned in last column of Table 1 were considered for determining the efficiency of treatment

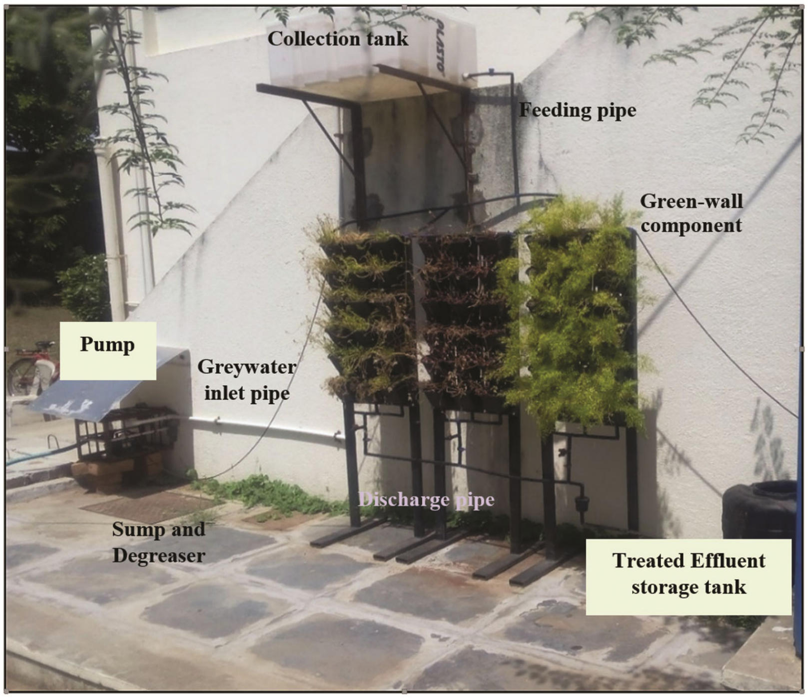


Fig. 3 — Experimental set up for greywater treatment

Table 1 — Variation in physico-chemical characteristics of raw greywater

Parameters	Units	Raw greywater (range)[15]	*Actual observed range	Design values
pH	-	6.5-8.5	7.8-8.5	8.0
TSS	mg/L	10-120	50-120	120
BOD	mg/L	45-150	48-70	70
COD	mg/L	—	64-92	90
Oil & grease	mg/L	—	20-30	30
Alkalinity	mg/L	—	110-130	130
Phosphate	mg/L	0.5-5	0.5-0.65	0.65
TKN	mg/L	—	15-30	30
Conductivity	µs/cm	150-500	120-300	300

*Existing studies

Table 2 — Concentration (CFU/ 100 mL) ranges of indicator bacteria reported in untreated greywater

Sources of greywater	Total coliform	Thermotolerant coliforms	Faecal enterococci	Escherichia coli
	Reference 21			
Hand wash/washbasin	2.4×10^2– >2.4×10^6	—	0 – 2.4×10^6	0 – 2×10^4
Bath/showers/wash basin	2.5×10^2 – >1.8×10^8	0 – 0.5×10^3	10 – 10^5	10 – 10^5
Laundry/ kitchen sink	7×10^5	7.3×10^2	—	—
Greywater (except toilet/kitchen)	10^2 – 10^6	10^2 – 10^6	10 – 10^5	—
	Existing studies			
Shower/bathing*	260 – 400	—	150-350	—

*Existing studies

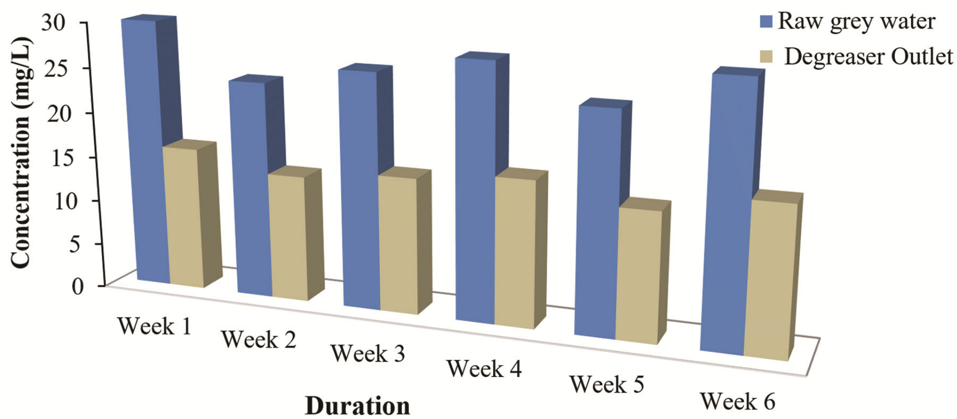


Fig. 4 — Performance of degreasing tank for oil & grease removal

Table 3 — Characteristics of greywater after degreasing tank

Parameters	Raw greywater	Outlet of degreasing tank	Removal efficiency (%)
pH	8.0	7.8	-
TSS	120	100	17
BOD	70	48	31
COD	90	68	24
Oil & grease	30	16	47
Total phosphate	0.65	0.63	3
TKN	30	28	7

system. Following sections describe the adequacy assessment studies of Green-wall system under different operating system.

Since the greywater had oil and grease content of the order of 24 – 30 mg/L, which could cause choking of filler material, hence it was planned to provide a degreasing tank to substantially remove oil and grease in feed greywater. Initially, the greywater was fed to degreasing tank for six weeks to assess the performance with respect to oil & grease removal. Fig. 4 depicts the performance of degreasing tank for oil and grease removal. It was observed that the oil and grease reduction varied in the range of 42 – 47 %. Characteristics of greywater obtained after degreasing tank are presented in Table 3. It was observed that degreasing tank also reduces 17% TSS, 31% BOD and 24% COD, while removal of TKN and total phosphate was 7% and 3%, respectively. Thus, provision of degreasing tank is very useful, especially for oil and grease laden greywater.

Performance assessment of the treatment system

For reuse, treated greywater quality must comply with the stipulated regulatory norms/standards/ guidelines values. However, at present there are no prescribed reuse guidelines in India, hence standards for various non-potable purposes as shown in Table 4 have been used for comparison[22].

Stage I (with LECA as filling material)

In Stage-I, the pots were filled with an inert filler material LECA, of size varying between 4 and 10 mm diameter and plant species were fed with treated greywater after degreasing tank. The performance of Green-wall was studied for six weeks for various parameters including BOD, TSS, COD, TKN, TP and oil & grease at various loading rates. Initially, Green-wall was subjected to a maximum allowable hydraulic retention time of 12 h, which resulted in flow rate of 100 L/d. Performance of Green-wall at 12 h HRT with respect to BOD and TSS is illustrated in Fig. 5. It was observed that BOD concentration for landscape irrigation was higher than the permissible limits of 10 mg/L as per treated greywater reuse norms[22] (Table 4). However, for BOD and TSS concentrations were well within the prescribed limits for agricultural reuse norms. Even though there are no prescribed standards for treated greywater for COD, TKN, TP and oil & grease, these parameters were also studied to assess the overall performance of Green-wall for organic matter and nutrient removal. Some of the past studies also resonate with the findings of existing studies. Ana Gavalo et al.[23] (2022) reported greywater treatment using Green-wall in which two different types of recycled materials viz. crushed tiles and textile fibers, were used as filling media along with Adiantum fragans and Davallia tyermanii. The authors observed that the crushed tiles mixed with coconut fibers in a 70:30 %ratio and textile fibers with plants indicated >70% removal efficiency for

COD and between 59 –70 % for TSS, whereas 60 and 50% removal efficiency was observed for COD and TSS, respectively, for fibers systems and clogging was prominent at the end of the study.

the performance of Green-wall using four common plant growing media viz. perlite, coco coir, LECA and sand, and compared with two new locally available media date seeds and spent coffee grounds (SCG). They reported that SCG is an excellent media for greywater treatment, providing a similar degree of treatment as the best traditional media, coco coir and providing improved drainage.

As shown in Fig. 5, BOD concentration at the end of 6th week was 10 mg/L (equivalent to the prescribed limit for landscape irrigation), thus indicated that the need for increasing the retention time for improving the performance. Similarly, COD and TKN reductions were also studied and it was observed that the removal efficiencies varied between 47–50% and 42–46%, respectively. Fig. 6 presents performance of Green-wall for COD and TKN removal. Analysis of total phosphates and oil & grease at the outlet of Green-wall revealed reduction in the range of 46–49% and 13–29%, respectively. Average phosphate concentration reduces from 0.60 to 0.33 mg/L and oil & grease reduces from 15.17 to 11.50 mg/L. Performance of Green-wall for phosphates and oil & grease are presented in Fig. 7. This indicated that, it is essential to provide oil & grease removal prior to Green-wall system owing to its low efficiency. Therefore, degreasing tank plays major role in removing oil & grease from greywater at the primary stage.

The performance assessment of Green-wall using LECA indicated satisfactory performance with respect to COD, TKN and TP, however in terms of BOD, it would require further treatment. The retention time in Stage I was not adequate as the greywater drains out easily, thereby reducing the contact time of greywater with media and plant species. Therefore, to reduce the drainage of greywater from pots, it was necessary to use other media along with the combination of LECA to increase the water retention and subsequently treatment efficiency of the system. Hence, Cocopeat was used with LECA in equal proportion, to increase the water retention time. The modified treatment system was studied as Stage-II.

Stage-II – LECA and cocopeat

In Stage-II, the LECA media was mixed with cocopeat in equal proportion to overcome the

Table 4 — US EPA Reuse Water Standards for various non-potable purposes[22]

Reuse options	pH	BOD (mg/L)	Turbidity (NTU)	TSS (mg/L)	Faecal Coliform (CFU/ 100 mL)	Residual Chlorine (mg/L)
Landscape Irrigation	6 – 9	10	2	—	0	1
Agriculture	6 – 9	30	—	30	200	1
Toilet Flushing	6 – 9	10	2	—	0	1
Ground Water Recharge	6. 5– 8.5	—	2	—	0	1

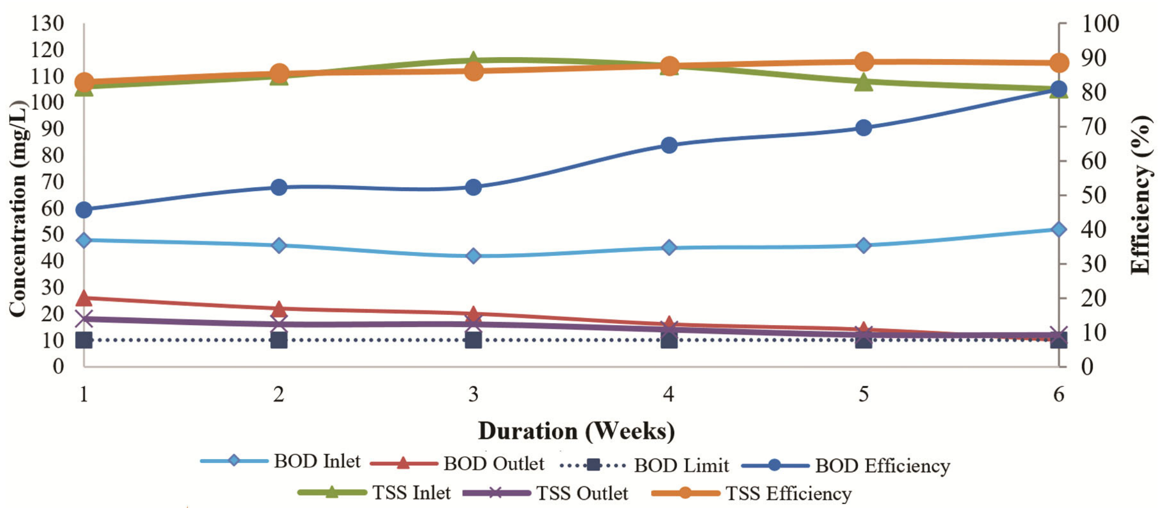


Fig. 5 — Performance of Green-wall at 12 h HRT for BOD and TSS removal; Stage-I (LECA as filling material)

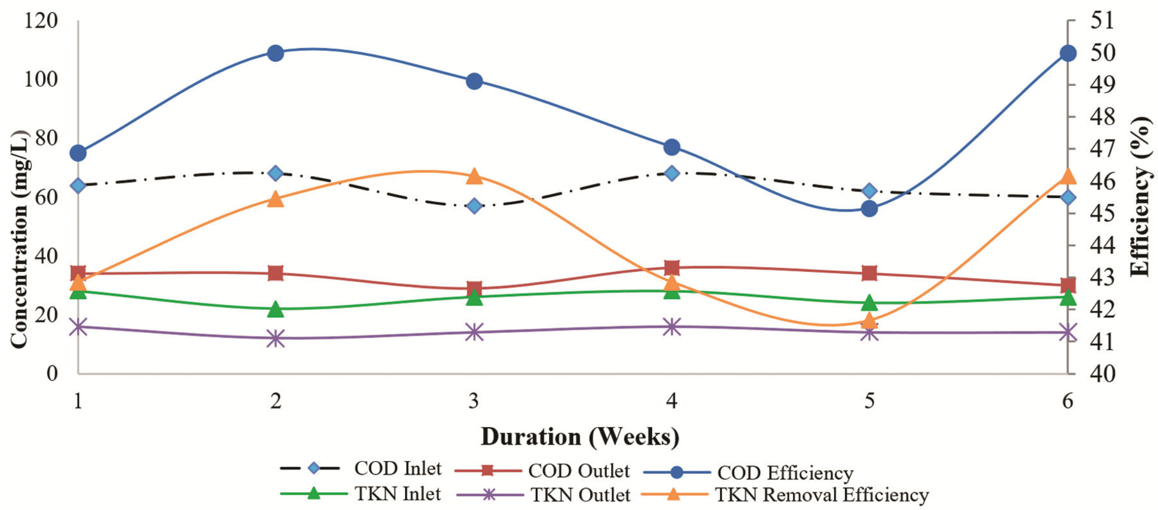


Fig. 6 — Performance of Green-wall at 12 h HRT for COD and TKN removal; Stage-I (LECA as filling material)

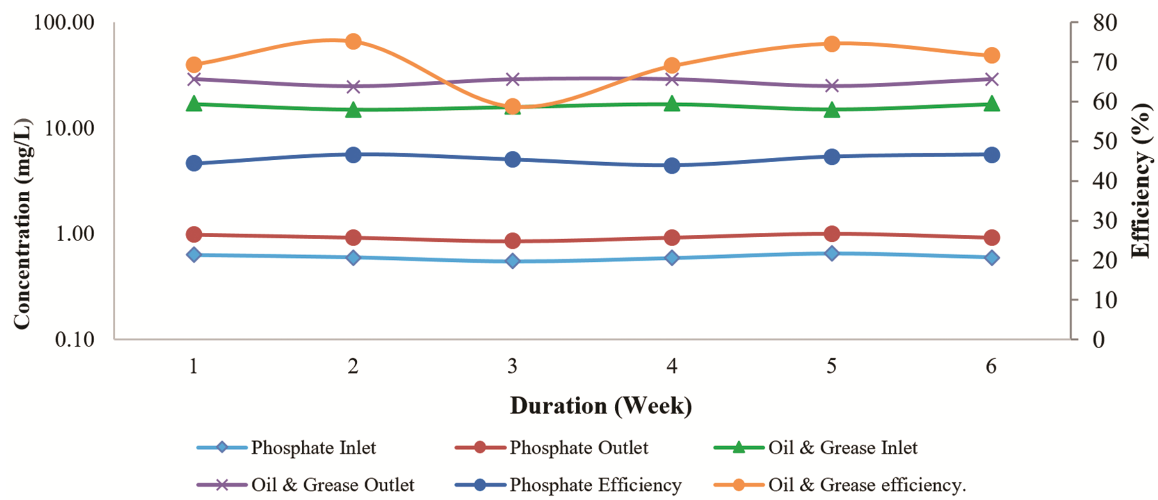


Fig. 7 — Performance of Green-wall at 12 h HRT for Phosphate and Oil & Grease removal; Stage-I (LECA as filling material)

limitation of low water retention observed in Stage-I. The Green-wall system during Stage-II was operated at various retention times, starting from HRT of 18 h and then reducing at an interval of 2 h to study the effect of increase in hydraulic load. The system was operated at 18, 16, 14 and 12 h to arrive at the optimized performance. Studies at various HRTs were carried out till the duration, when a steady performance was achieved. This period extended between 12 and 20 days. Accordingly, performance of Green-wall for various parameters represents average concentrations at a particular HRT. Fig. 8 presents performance of Green-wall with respect to TSS and BOD at various operating conditions.

It was observed that with increase in hydraulic loading, efficiency of Green-wall reduces. Effluent TSS and BOD concentrations at 18 h HRT were found quite less than that at 12 h HRT. Outlet TSS & BOD concentrations at 18, 16, 14 and 12 h were 10, 8, 6, 4 mg/L and 16, 10, 08, 06 mg/L, respectively. Efficiency of Green-wall for TSS and BOD removal decreases from 96 to 91% and 88 to 67%, respectively, due to reduction in HRT from 18 to 12 h. However, TSS and BOD efficiencies at HRTs 16 & 14 h were 94 & 93% and 75 & 76%, respectively, indicating marginal variation in efficiency. BOD concentrations at 16 & 18 h HRTs were well below the permissible limits for landscape irrigation, whereas TSS concentrations were below the permissible limits for all the HRTs for agricultural reuse standards. This reveals that combination of LECA and cocopeat provides higher water retaining and hence higher HRTs, which enhances

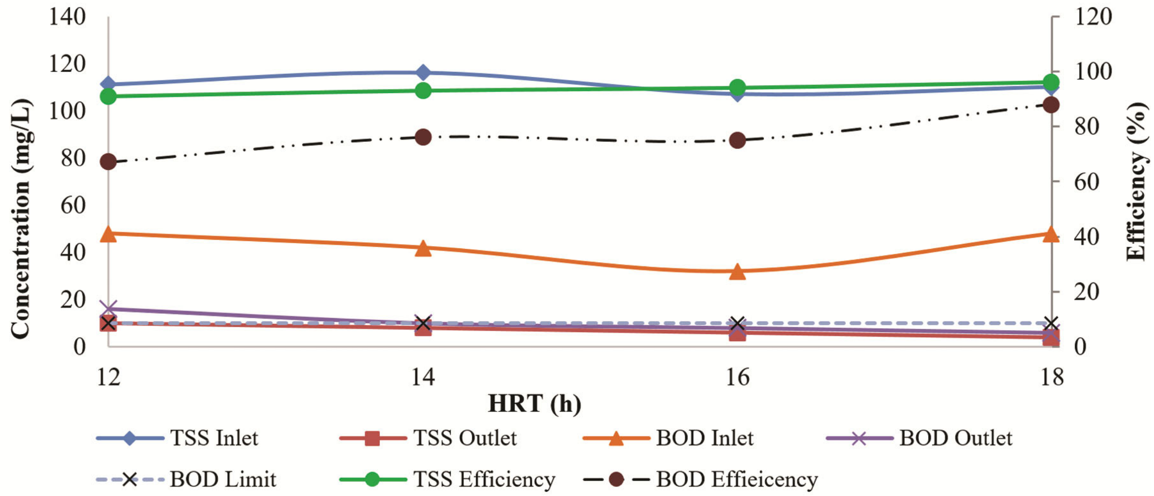


Fig. 8 — Performance of Green-wall at various HRTs for BOD and TSS removal; Stage – II (LECA + coconut peat as filling material)

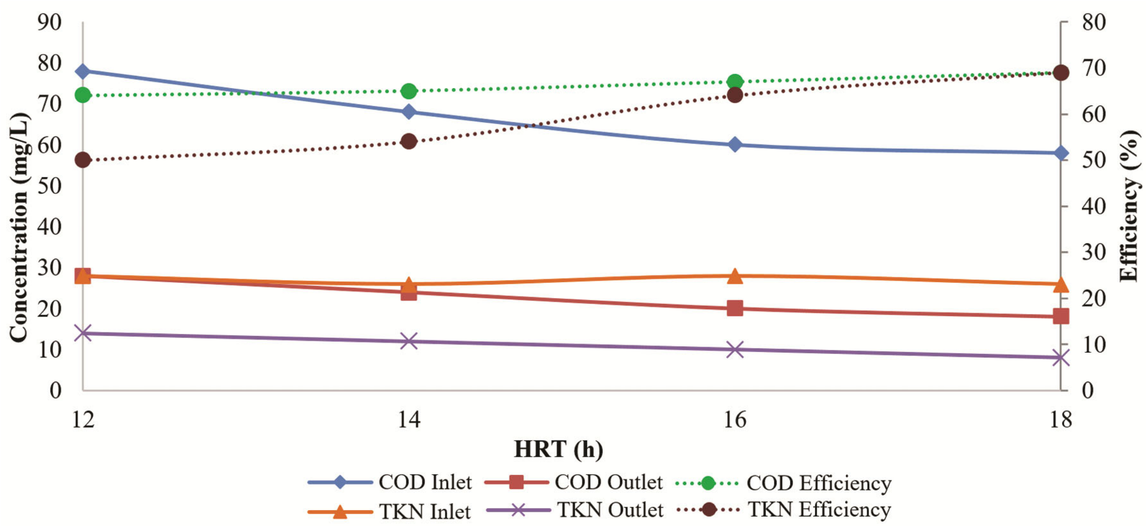


Fig. 9 — Performance of Green-wall at various HRTs for COD and TKN removal; Stage – II (LECA + coconut peat as filling material)

the performance of Green-wall. Fig. 9 presents performance of Green-wall with respect to TKN and COD at various operating conditions. Effluent TKN and COD concentrations at 18 h HRT reduce from 26 to 8 and 58 to 18 mg/L, respectively, whereas at 12 h HRT it was found to reduce from 28 to 14 and 78 to 28 mg/L, respectively. Efficiencies of Green-wall with respect to TKN and COD removal at 18, 16, 14 and 12 h HRT were 69, 64, 54, 50% and 69, 67, 65, 64 %, respectively. Fig. 10 presents performance of Green-wall with respect to phosphates and oil & grease removal at various operating conditions. Effluent phosphates and oil & grease concentrations at 18 h HRT reduce from 12 to 9 and 0.68 to 0.25 mg/L, respectively, whereas at 12 h HRT it was found to reduce from 12 to 10 and 0.6 to 0.3 mg/L, respectively. Efficiency of Green-wall with respect to phosphates and oil & grease removal at 18, 16, 14 and 12 h HRT were 63, 60, 56, 50 % and 25, 25, 21 & 17 %, respectively.

Results of oil & grease removals at various HRTs during Stage-I and Stage-II studies indicate that Green-wall is not efficient for oil & grease containing greywater owing to poor removal efficiency, hence substantial removal of oil & grease through degreasing tank is necessary, where 42-47% of removal efficiency was observed.

Treatment of greywater using degreasing tank and Green-wall system indicated optimized performance at 16 and 18 h HRT (hydraulic loading rate 67 - 70 L/m^2/d), as compared to 14 and 12 h HRT. The treated greywater quality met the prescribed permissible limits with respect to BOD and TSS and

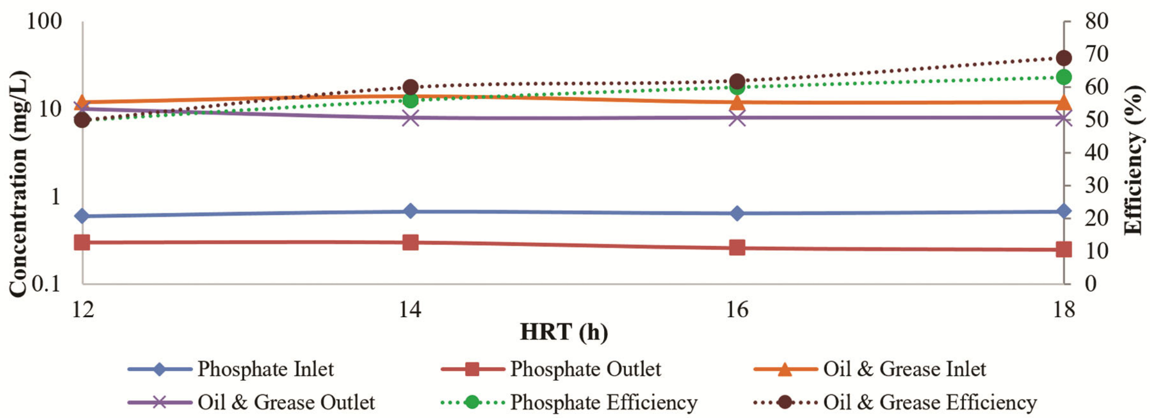


Fig. 10 — Performance of Green-wall at various HRTs for Phosphate and Oil & Grease removal; Stage – II (LECA + coconut peat as filling material)

was observed to be innocuous in terms of the reuse options for agriculture and landscape irrigation. Further, it is imperative to have disinfection prior to reuse for any no-potable use. In the present study, total faecal counts in raw greywater were less than 400 CFU/ 100 ml (Table 2) and were non-detectable in final treated greywater. However, chlorine dose of 0.5 mg/L was added to the treated greywater prior to reuse for gardening purpose.

Conclusion

The concept of greywater reclamation using Green-wall for small communities significantly reduces dependence on fresh water demand for agriculture and landscape irrigation. An integrated approach of degreasing and vertical Green-wall systems play important role in removing oil & grease and organic matter & suspended solids, respectively. It is pertinent to note that Green-wall sizing would largely depend on site specific conditions and greywater characteristics. In the present study, maximum achievable retention time in Stage-II was 18 h, giving hydraulic loading rate of 67 L/m^2/d. At this hydraulic loading rate, Green-wall system indicated optimized performance and the treated greywater quality met the prescribed permissible limits vis-à-vis USEPA (2012)[22] standards with respect to pH, BOD, TSS and faecal coliforms and was observed to be innocuous in terms of reuse options for agriculture and landscape irrigation.

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