Original Research Article

Greywater treatment by vermifilter: A low-cost option for rural sanitation in India

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Abstract

Recycle and reuse are the best options to deal with water scarcity. An attempt is made to reuse greywater after giving low cost effective treatment with the help of vermifilter. Vermifilter is an emerging technology in which combined action of earthworm activity and the adsorption properties of material like soil, sand and gravel particles on the organic pollutants applied for greywater treatment. The present study addresses performance evaluation of a laboratory scale vegetated vermifilter system comprising of settling tank, sand-gravel filter (SGF), Laterite soil vegetated filter (LSVF) and laterite soil vegetated vermifilter(LSVVF) for the treatment of greywater. The sequential batch experiments were conducted in a pilot scale experimental set-up. The Organic loading rate (OLR) was varied from 20 to 140 kg BOD/ha/d and the hydraulic retention time (HRT) used was from 0.50,1,2 and 3 d. The BOD_5 removal efficiency was found to be in the range 15–30%, 48–60 %, and 70-80 for 3 d HRT in SGF, LSVF and LSVVF respectively. The efficiency of the system for BOD_5 removal was observed to be 75–85% at 3 d HRT. The effluent can be recycled and used for non-potable purposes in a household. The developed system is a potential option for the decentralized wastewater treatment in developing country like India.

Key Words: *Eisenia fetida, Canna indica*, laterite soil vegetated filter (LSVF), laterite soil vegetated vermifilter filter (LSVVF), Laterite soil.

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INTRODUCTION

The stress on water usage, sanitation and wastewater disposal has increased due to the increase in population. Water can be classified as freshwater, saltwater, greywater, and black water. Greywater represents the most profitable source in terms of its reliability, availability and quality. The principal contributions to greywater include water from bathing and cloth washing activities. The composition of greywater from Indian town/cities showed low strength of wastewater. Due to rapid industrialization and development, there is an increased opportunity for greywater reuse after treatment in developing countries such as India. The reuse and recycling should begin at each and every residential, commercial, and industrial building. Therefore it is necessary to develop low-cost greywater treatment system producing recyclable/reusable water at household level. The greywater treatment options used include physical, chemical and biological systems. The physical treatment consists of screening, and gravel-sand bed filter. Chlorination and photocatalytic oxidation were the chemical treatment. The systems viz. Membrane Bio-Reactor (MBR), Upflow Anaerobic Sludge Blanket Reactor (UASBR), Rotating Biological Contactor (RBC) and Constructed Wetland (CW) have been used as biological options. Biological processes, which range from state-of-the-art MBR to low-tech CWs systems, are considered most appropriate for treatment of grey water because of their efficient removal of organics. The combination of biological system with physical filtration is considered to be the most economical and feasible

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solution for greywater recycling. MBR has demonstrated the capacity to produce high quality effluent[1,2]. However, other researchers reported that MBR and RBC are inappropriate[3]. The UASBR system has been successfully adopted to treat greywater. However, adoptability of anaerobic treatments is restricted to high strength wastewater. CWs have been used successfully in the past for the treatment of wastewater. Physical, chemical and biological processes are combined in CWs to remove contaminants from wastewater. Numerous studies describe use of CWs for greywater and wastewater treatment demonstrated use of aerated constructed wetland (ACWs) in wastewater treatment[3,4,5,6,7,8,9,10,11]. Zhao (2010) carried out experiments to access potential applicability of ornamental plants like Canna indica and Heliconia are used in the CW to increase their aesthetic value[12]. The VF is an improved soil filter colonized by earthworms and bacteria. The soil provides a platform for earthworm development and movement in the VF. Vermifiltration of wastewater using earthworms occurs by the general mechanism of ingestion and biodegradation of organic waste, heavy metals and solids from wastewater, and also by their absorption through body walls. The studies carried out to treat wastewater/sludge using earthworms include Bhawalkar (1996), Taylor *et al*. (2003), Munavalli and Phadatare (2006), Sinha *et al*. (2008), Kadam *et al*.(2009), Dhadse *et al*. (2010), Wang *et al*.(2010a, b), Xing *et al*. (2010), Wang *et al*. (2010 c, d), Xing *et al*. (2011) and Li *et al*. (2011)[13,14,11,15,16,17,18,19,20,21,22,23,24] It can be seen from reviewing the literature that the CW and VF systems have been separately adopted for the efficient treatment of domestic wastewater. However, there is a need to develop/assess the performance of laterite soil vegetated filter and laterite soil vegetated vermifilter. In the present study, laboratory scale vegetated vermifilter consisting of primary treatment (settling tank and sand-gravel filter (SGF)), secondary treatment (LSVF and LSVVF) with use of *Canna indica* vegetation and *Eisenia fetida* was developed. The performance evaluation studies were carried out at various stages of treatment for varied organic loading rate (OLR) and hydraulic retention time (HRT).

MATERIALS AND METHODS

Greywater Source: Greywater from boy's hostel in the campus of Rajarambapu Institute of Technology (RIT), Rajaramnagar (M.S., India) was used as a feed for the present study. The hostel accommodates 150 students and having 24 bathrooms and 24 water closets. The major contribution to greywater is from bathrooms.The toilet flush is diverted to septic tank and bathroom wastewater is collected separately. The grab samples of greywater stream were collected for characterization. In order to ensure uniform quality of greywater the grab samples were collected 10 am in the morning of each of the sampling days. The settled greywater was used as a feed to pilot scale greywater treatment plant.

Earthworm and Canna Indica vegetation: Individuals of earthworm *eisenia fetida* of different age group were collected from composting plant of Rajarambapu Sugar Factory, Rajaramnagar, (M.S., India). *Canna indica* vegetation used for development of bio-filtration unit was collected from natural drains of Islampur city.

Experimental set-up: The objectives of the system were to remove suspended solids and dissolved organic matter. The processes used in the experimental setup include settling, filtration, decomposition and adsorption. The suspended solids are removed in a settling tank and also in a VFSGF. The removal of dissolved organic matter occurs by means of the attached growth system in a SGF and the attached and suspended growth system in an LSVF and LSVVF. An aerobic environment is maintained within the LSVF. The developed experimental setup has a logical sequence of primary and secondary processes. Figure 1 shows a schematic sketch of the lab-scale treatment system with flow regulation valves. It consists of four units: settling cum equalization tank, SGF, LSVF and LSVVF. Figure 2 shows Photographic View of Experimental Setup of Vegetated Vermifilter.

Figure 1: Schematic Diagram of Laterite Soil Vegetated Vermifilter a) Side View b) Front View

Figure 2: Photographic View of Experimental Setup of Vegetated Vermifilter a) Side View b) Front View

Each unit has a capacity of 150 L and depth of 54 cm. The settling unit allows the coarser solids to settle out and equalize the quality of feed greywater. In order to refine the quality of feed water to the LSVF and LSVVF, the SGF was provided. It is a graded upflow filter with gravel at the bottom and sand at the top. The details of filter are given in Table 1. The secondary treatment is in the form of a LSVF and LSVVF. The details of LSVF and LSVVF filters are given in Table 2 It has laterite soil and pebbles as a supporting medium vegetated with Canna with and without earthwarm.

Table 1: Details of Vertical Flow sand filter

Sr. No	Material	Size (mm)	Depth(m)
1	Gravel (Bottom)	12.50-20	0.20
2	Gravel (middle layer)	8-12.50	0.20
3	Coarse sand(middle layer)	4.75	0.20
4	Fine sand (Top)	0.075-1	0.20

Table 2: Details of laterite soil vegetated filter and Vermifliter

Sr. No	Material	Size	Depth(m)
1	Lateritic soli (Top)	0.075 mm-1 mm	0.15
2	Laterite gravel (middle layer)	6-12.50 mm	0.15
3	Laterite gravel (middle layer)	12.5-25 mm	0.15
4	Laterite gravel (Bottom)	25-50 mm	0.15

Operation of the system: The various units in the treatment system were arranged in such a way that a gravity flow was maintained through the system. The VFSGF, LSVF and LSVVF were operated in up flow and down flow modes, respectively. The system was operated in sequential batch mode. The steps involved in the operation are described below:

1. Initial trial runs were conducted to relate flow, HRT and extent of outflow valve opening in settling tank. The results of these trial runs were used to mark the valve opening positions for various HRTs to be achieved in the system.
2. The settling tank was filled with greywater with the outflow valve closed. A settling time of 30 minutes was allowed.

3. The outflow valve of settling tank was opened to the extent required to achieve a specified HRT thereby feeding the SGF at the bottom.
4. The flow from the SGF enters continuously into the LSVF and LSVVF at the top and was spread uniformly until the closure of the outflow valve of settling tank. After the stoppage of flow from the settling tank, there is a drawdown of wastewater level in the LSVF and LSVVF.
5. The secondary effluent from SGF was fed uniformly by the drip system to the secondary system, which works in the down flow mode. The secondary effluent first moves through VF The secondary effluent were collected in a closed container.
6. Steps 2 to 5 were repeated for each of the batches. The organic loading was varied and each of the organic loading for a specified HRT constituted a batch.
7. The required amount of settled feed greywater was collected for analysis. The flows from SGF, LSVF and LSVVF were collected through the sampling ports in the respective units on a daily basis and analyzed.

Planning of experiments: The experiments were planned in two phases: initial and established. The initial phase was the period when the vegetation grew to a certain height and roots developed. In this phase, groundwater was used as feed water for the growth of vegetation. The established phase was when vegetation had grown to a sufficient height so that it could sustain and treat the wastewater. In this phase, the treatment system was evaluated for its performance in treating the greywater. The feed greywater was collected daily from a boy's hostel of RIT, Rajaramnagar Sangli (MS-India). The organic loading was varied and the performance was assessed in terms of organic matter (biochemical oxygen demand; BOD5). The organic loading was calculated for each of the units (SGF, ACW and VF) separately. The experiments were planned for organic loading in the range 20–110 kg/ha d and HRT between 1 and 3 d. pH was determined to detect the effect within the system. The procedures to analyze these parameters were according to Standard Methods [25]. pH and turbidity were determined by electrometric and nephelometric methods respectively.

RESULTS AND DISCUSSION

Greywater characterization: The characterization of greywater was carried out throughout the study period and characteristics for period are given in Table 3. The results show that BOD_5/COD ratio was in the range 0.68 to 0.80 indicating amenability of greywater for biological treatment. It can also be seen that the quality of raw greywater was uniform throughout the study period. The other characteristics show that the greywater is nearly neutral, low in ionic strength, and turbid. The presence of pathogens in raw greywater is a significant observation. The line of treatment for this quality should include removal of suspended solids, organic matter and pathogens.

Table 3: Characteristics of Raw and Treated Greywater

Sr. No.	Parameter	Unit	Raw GW	SGF TGW	LSVF TGW	LSVVF TGW
1	pH	-	7.85±0.45	7.54±0.30	7.38±0.21	7.26±0.16
2	Acidity	mg/L	170±24	124±17	75±12	54±10
3	Alkalinity	mg/L	308±42	222±29	131±30	98±24
4	Chloride	mg/L	387±33	190±33	113±19	86±15
5	$BOD_5 20^oC$	mg/L	130±17	95±12	46±7	30±6
6	COD	mg/L	190±24	133±20	74±10	50±10
7	EC	μS/cm	1035±82	716±94	360±78	232±52
8	TDS	mg/L	696±66	498±64	251±62	166±36
9	Turbidity	NTU	18±2.2	10±0.80	4.5±1.5	2.11±0.80
10	Temperature	ºC	28±1.4	27±1.40	27±1.4	27±1.4
11	TKN	mg/L	17±2.5	12±1.80	7.11±.1.0	4.67±.0.80
12	MPN	No./100 ml	78±24	39±10	22±4	19±4

Pre-Treatment: The quality of greywater after equalization and SGF system is given in Table 3. Fig. 4.3 showed the removal of turbidity, BOD_5 removal throughout the study period. The results showed that there is an average reduction in turbidity was 55% and BOD_5 was 21%. There is no significant variation/removal observed in other parameters. The turbidity removal is relatively more consistent (60% to 75%) during the study period. This is due to maturation of the system in terms of suspended solids accumulation in the voids and availability of uniform area for flow. Organic matter removal is more consistent in the range 20% to 30% in the study period. The soluble portion of BOD_5 from greywater is removed by attached and suspended growth microbes. The mechanisms involved in BOD_5 removal include adsorption and biological degradation by attached growth bacteria. A thin slimy layer was observed around the extracted sand particles from the SGF bed. Whereas, there is no detailed microbiological studies of this biofilm were done. The removal of suspended solids in SGF was by straining mechanism. The surface area was provided by SGF for bacterial attachment to remove dissolved organic matter biologically. Pre-treatment used in this study has a potential to refine the quality of greywater suitable to the desired quality as a feed for the LSVF and LSVVF system. The size of the gravel and sand used in this study were appropriate as no clogging problems were observed throughout the study period and hence are recommended for pre-treatment.

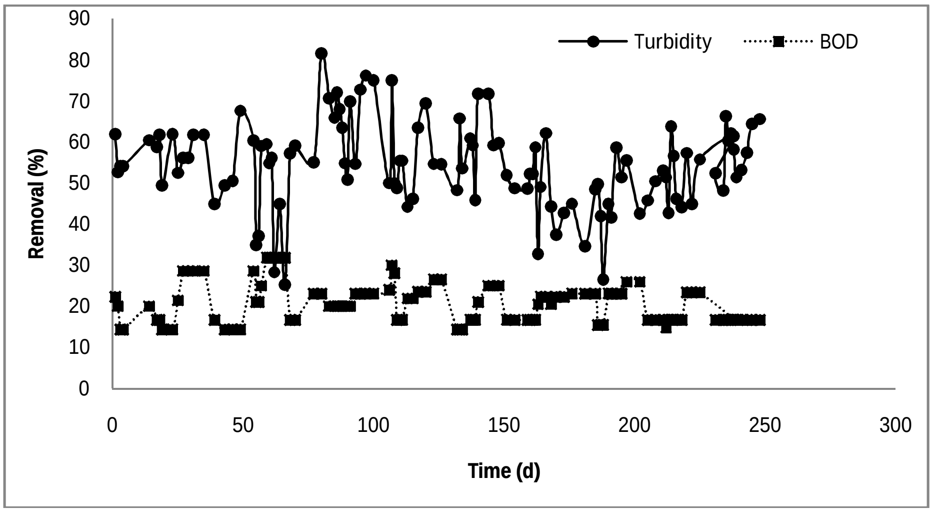

Figure 3: Temporal Variation of Turbidity and BOD_5 removal in Pre-Treatment

LSVF and LSVVF: The performance of the LSVF and LSVVF was evaluated for the removal of organic matter and the variation in pH was monitored.

pH: Figures 4, 5 and 6 show the variation of pH with organic loading in the SGF, LSVF and LSVVF respectively. It can be seen that there is a slight decrease in the pH value in the effluents compared to the respective influents. The decrease in pH was observed to be increasing with increase in Organic loading rate (OLR). The pH of effluents varied in the range 7.10–7.65 during the period of study. The observed pH range was conducive for the bacterial and earthworm activity.

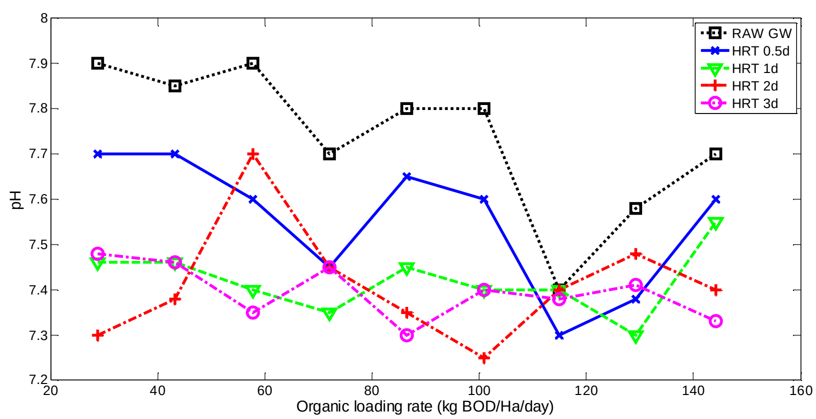

Figure 4: Variation pH with organic loading rate in VFSGF

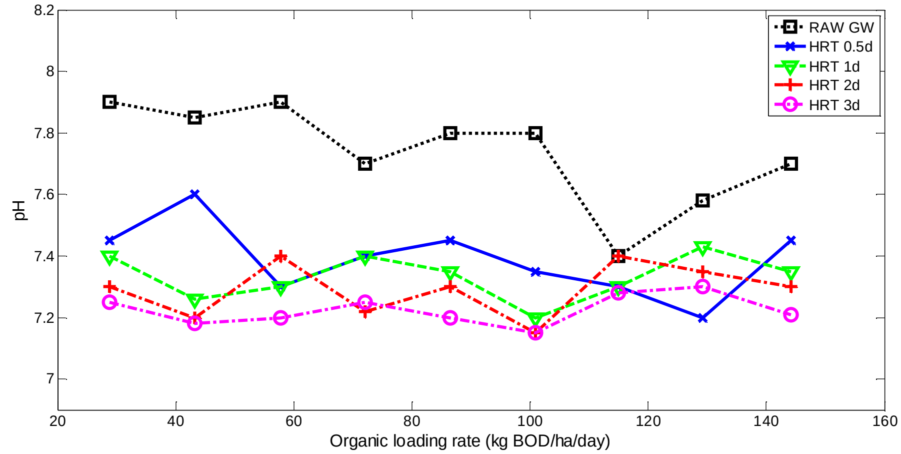

Figure 5: Variation pH with organic loading rate in LSVF

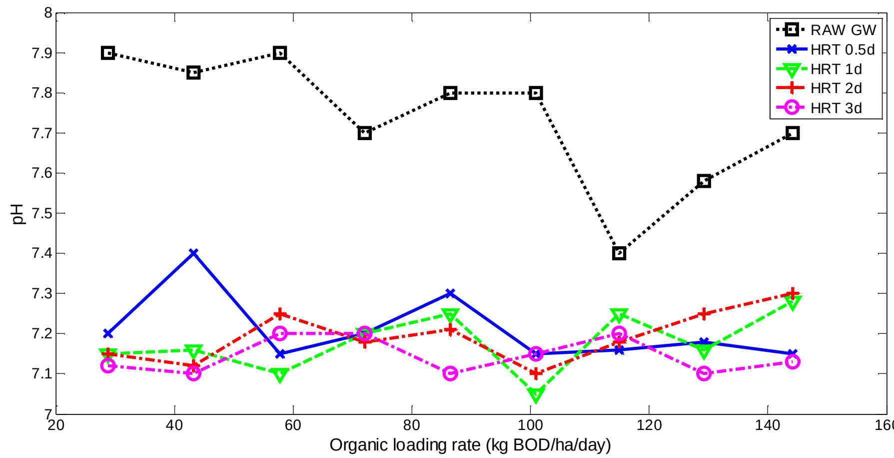

Figure 6: Variation pH with organic loading rate in LSVVF

BOD 5: Figures 7, 8, 9 and 10 show the variation of BOD5 and its removal from LSVF and LSVVF with organic loading for HRT of 0.5,1, 2 and 3 d respectively. The organic loading in the figure refers to the organic loading on the LSVF and LSVVF computed separately. It can be seen that the BOD5 removal increases with increase in HRT. However, HRT of 3 d was found to be adequate for reducing BOD5 to a value less than 20 mg/L. Figure 11 shows overall BOD5 removal from the treatment system for HRT 3 days. The overall efficiency of the system for BOD5 removal for 3 day HRT from various treatment units are LSVF observed to be 50–60%, and LSVVF 60–80% and total efficiency 80–90%).The BOD_5 removal in LSVVF was 60–80%.Organic matter removal occurs in the LSVVF due to the combined actions of soil, earthworms. BOD5 is removed from the greywater by earthworms; the enzymes in the gut of earthworms help in the degradation of several of those chemicals which otherwise cannot be decomposed by microbes. Earthworms intensify the organic loadings of greywater in the LSVVF soil bed by the fact that they granulate the clay particles thus increasing the 'hydraulic conductivity' of the system. They also grind the silt and sand particles thus providing high total specific surface area, which enhances the ability to adsorb the organic and inorganic matter from the greywater passing through. The microbes play an important role in a vermi-biofiltration system and they also provide some extracellular enzymes to facilitate rapid degradation by earthworms of organic substances in vermibeds. Earthworms and aerobic microbes act symbiotically to accelerate and enhance the decomposition of organic matter. The soil and small stones of the VF bed and microbial system in the control biofiltration unit are responsible for chemical oxygen demand reduction while in the vermi-biofiltration system enzymes, secreted by earthworm and gut-associated microflora reduce those chemicals which otherwise cannot be decomposed by microbes [26]. Studies on microbial diversity and structure in vermifiltration were carried out by Wang [21,22]. The earthworms were used for the treatment of greywater.

The results of these studies indicate that survival of earthworms in greywater is not a major issue provided the worms acclimatize to the conditions within the treatment system, no detrimental effect on earthworms was observed in the present study.

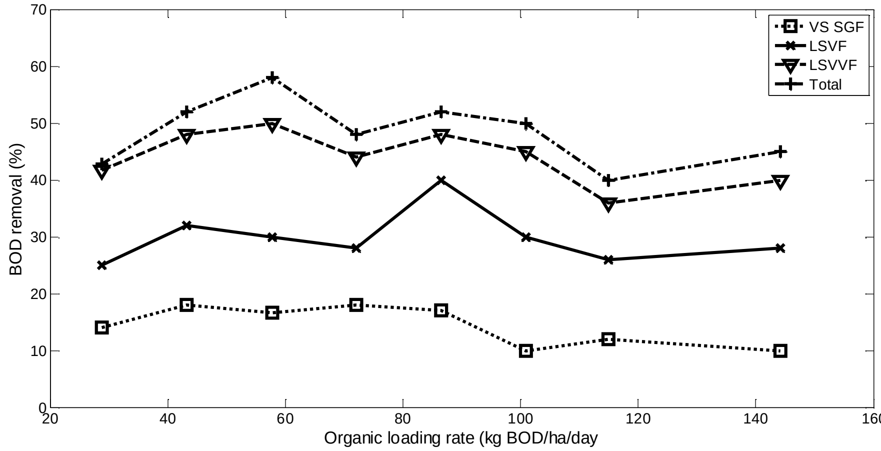

Figure 7: BOD removal from various units for HRT-0.50 day

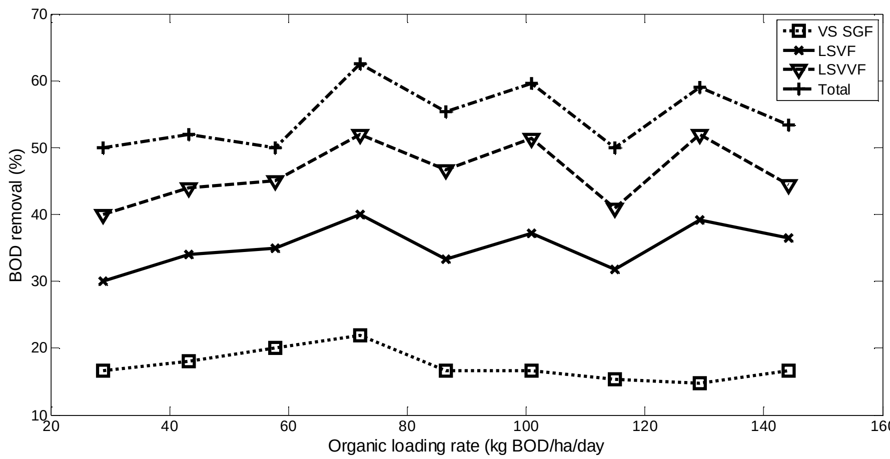

Figure-8 BOD removal from various units for HRT-1 day

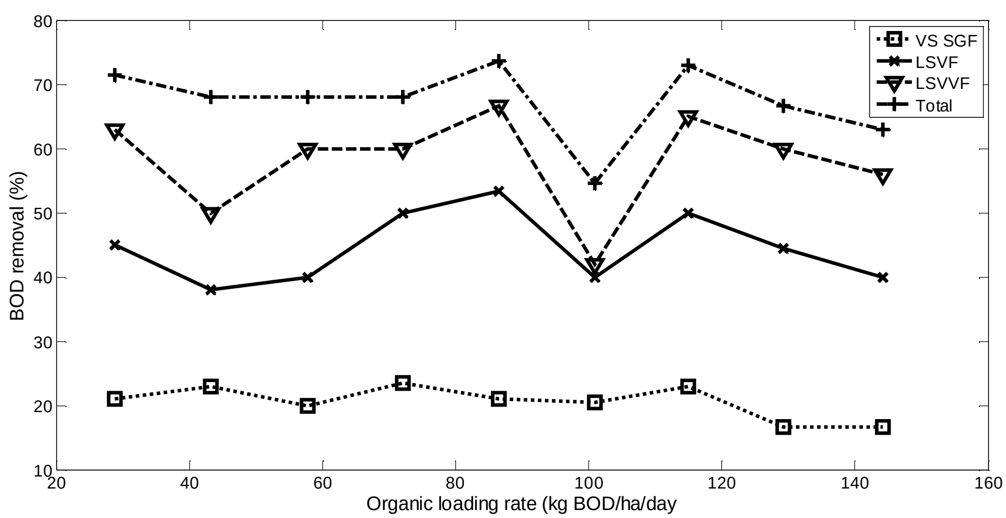

Figure 9: BOD removal from various units for HRT-2 day

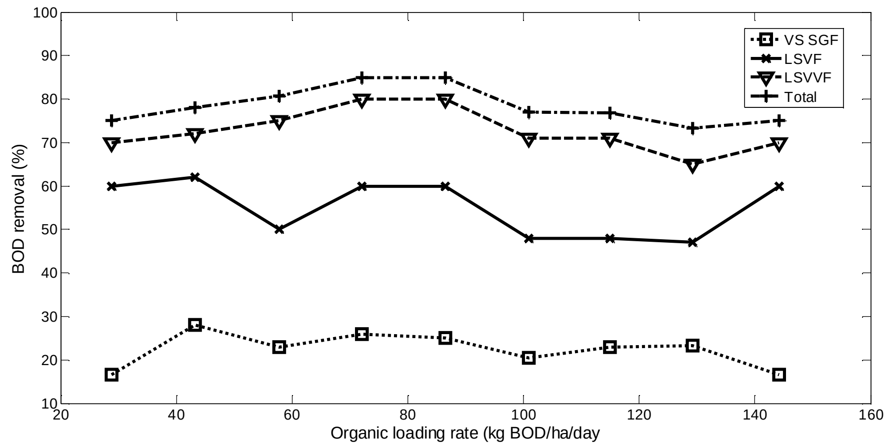

Figure 10: BOD removal from various units for HRT-2 day

CONCLUSIONS

A laboratory scale vegetated vermifilter consisting of SGF, LSVF and LSVVF for the treatment of greywater was developed. The developed treatment system was evaluated for its performance by varying organic loading and HRT. The turbidity of filtrate can be reduced to a value less than 2.1 NTU by the SGF. The organic loading and HRT (1–3 d) do not affect the BOD_5 removal in the SGF significantly. The contribution by the SGF to BOD_5 removal is 20–30%. The mechanisms involved in BOD5 removal in the SGF include biofilm development, adsorption and decomposition. The LSVF and LSVVF treatment units of the developed system contribute significantly to increase in DO. LSVF and LSVVF contribute equally to the removal of BOD_5 to an extent of 70–80% each and aerobic conditions prevail in both. There is no detrimental effect on earthworm survival and growth due to the feeding of wastewater. The combination of SGF, LSVF and LSVVF performs efficiently for BOD_5 removal. HRT of 3 d for the system is appropriate for reducing BOD5 to a value less than 20 mg/L for an organic loading up to 110 kg BOD5/ha d. The effluent can be recycled and re-used for non-potable purposes within a household. The laboratory scale vegetated vermifilter is useful for the treatment of domestic wastewater at household level. It provides a low-cost, efficient, easily operable/maintainable and least mechanized option for wastewater treatment in a decentralized system.

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