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Original Research Article

Techno-Economic Evaluation of a Multi-Media Vertical Flow Filter for Roof water Harvesting

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Abstract

A vertical flow multimedia roof water filter was developed and tested for hydraulic efficiency and pollutant removal efficiency to meet drinking water standards. Along with sand and gravel, three types of adsorbents, viz, (coconut) shell charcoal, wood charcoal and anthracite were tested as filter media. Apart from these, three types of circular shaped screens such as nylon, aluminum and non-woven coir-sisal fabric screens were also tested. The filter media were filled in four different volume ratios, viz., 1:1:1, 3:2:1, 2:1:3 and 1:3:2.As a pre-treatment quality study of inlet water, the direct rainwater, roof water and runoff/ storm water samples were collected from two sites in Tamil Nadu and Kerala and were analysed for various physicochemical parameters. The roof water vertical filters were found to be highly effective in removing TS, K and PO_4^{2-}, normalizing pH and reducing EC. It had fairly good efficiency in removing NO_3^-. The removal percentage of Fe^{2+}, Na^+ and Ca^{2+} were low, while that of Mg^{2+} showed –ve value. A new terminology, UPI (Universal Performance Index), which represents the weighted average of the hydraulic efficiency and quality improving efficiencies, giving extra weight to the latter, has been introduced. Statistical analysis of UPI values for roof water filters showed that the proportion P3 (1:2:3), media M3 (anthracite) and screen S2 (aluminum mesh) were found to be the best. P1M3S2 (gravel-anthracite-sand in 1:1:1 proportion separated by aluminum meshes) emerged the best filter combination. Based on the estimated annual costs and returns, all the financial viability criteria (IRR, NPV and BCR) were found favourable and affordable for investment on developed filtration system.

Keywords

Economic analysis
Fabric screens
Filter media
Hydraulic efficiency
Pollutant removal efficiency
Vertical filter

Introduction

Rainwater harvesting consists of a wide range of technologies used to collect, store and provide water with the particular aim of meeting demand for water by humans and/or human activities. Though rainwater is considered as a contamination free source, human activities particularly in the industrial sector even pollute the clouds due to the generation of greenhouse gases, leading to acid rains. Besides upon incidence on the earth surface and generation as runoff, the rainwater undergoes a series of quality changes through contamination and pollution. The rainwater input, whether it is roof water or storm water runoff, contains a lot of impurities and contaminants as it flows through uncleaned roof surfaces or contaminated/polluted land surfaces. The major pollutants in case of roof water are organic in nature, while that of storm runoff are mainly silt load, residues of pesticides/weedicides or fertilizers, organic pollutants-both human and plant origin, heavy metals and other chemical load from industries. The quality of harvested water depends upon the end use; for example high standards have to be ensured for drinking water, but the quality can be low if the end use is for irrigation.

Roof water harvesting is a technology used for collecting and storing rainwater from rooftops, mostly in tanks. In domestic rooftop rainwater harvesting systems, rainwater from the house roof is collected in a storage vessel or tank for use during the periods of scarcity. Usually, these systems are designed to support the drinking and cooking needs of the family at the doorstep. Such a system usually comprises a roof, a storage tank and guttering arrangement to transport the water from the roof to the storage tank. In general, the quality of roof runoff is acceptable to supply low-quality domestic uses. Pollutant additions to roof runoff include organic matter, inert solids, fecal deposits from animals and birds, trace amounts of some metals, and even complex organic compounds. These form the essential nutrients for growth of bacteria. Factors such as type of roof material, antecedent dry period (atmospheric deposition) and surrounding environmental conditions (proximity of strong sources, such as motorways or industrial areas) are likely to influence concentrations of heavy metals in roof runoff (Forster 1996).

Rott and Mayer (2000) developed a system for testing filters as a part of the work surrounding the development of the German rainwater harvesting standard. The methods used by them worked well as a simple and repeatable test to characterize filters used in Europe for secondary water (i.e. water used for toilet flushing and clothes washing), providing a unified standard. Their standard load does not however realistically represent actual sediment loads in roof run-off water in low-income countries (Martinson and Thomas 2005).

Long et al. (2006) experimented engineering of a green roof media for water quality improvement over the rooftop with respect to nutrient and metals. They found the fine graded expanded shale consistently performed very well at sorbing pollutants common in rainfall. The Up-Flo™ stormwater filter technology, developed under the US EPA's Small Business Innovative Research (SBIR) program, incorporated elements of a treatment train approach including screening, sedimentation and high-rate filtration in a compact modular device (Pitt et al., 2008). Rasima et al. (2009) studied the efficacy of biofilm column and multimedia filtration systems which consist of granular activated carbon (GAC)-biofilm configured up-flow fluidized expanded bed (UFEB) reactor and slow down-flow packed sand bed reactor, in roof water harvesting systems. The multimedia filter showed efficient performance by removing 75.49 % of iron (Fe^{2+}) and 62.10 % of sulphate (SO_4^{2-}). Besides that, this experiment also showed the good performance in ammonia (NH_4^+), nitrate (NO_3^-) and nitrite (NO_2^-) removals. Areerachakul et al. (2009) used granular activated carbon (GAC) filtration as a pretreatment to microfiltration (MF) to remove the dissolved organic matter (DOC) in roofwater. The GAC system removed DOC by up to 40%, 35%, and 15% for bed filter depths of 15, 10, and 5 cm, respectively.

Martinson and Thomas (2005) reported the results of a series of laboratory tests on the abilities of simple filters to remove particulates from roof run-off water. The low-cost (<$5) filters tested were of stretched clothes. Self-cleaning and plain (debris-retaining) filter designs were compared. Each filter was tested with a standard contaminant load based on sand and Polyethylene sheet under a variety of representative flow rates. The initial tests showed that self-cleaning by using a sloping surface works satisfactorily and that simple cloth filters have a comparable performance to sophisticated filters found in German rainwater harvesting systems. However, the researchers suggested that the German test configuration used was found to poorly represent run-off water from the roof in tropical countries.

Though traditional methods of rain water collection are prevailing in some parts of the world, the system of harvesting, storing and reusing the harvested rainwater after quality enhancement with appropriate filtration mechanisms for various end uses viz., irrigation, drinking water, groundwater recharge etc. is comparatively a novel and innovative idea. In this context, this study was contemplated to develop an efficient filtration mechanism for roof water harvesting systems to enhance the quality of rainwater before it is diverted to storage tanks, especially for potable uses. The results of studies on performance evaluation of the developed vertical roof water filter consisting of fabric screens and filter media such as gravel, sand and charcoal are reported in this paper.

Materials and methods

A vertical flow filtration mechanism was designed, developed and evaluated as part of trial II for filtering rainwater flowing down from roofs of buildings. The filter was cylindrical in shape and could be used as inlet filter before rainwater harvesting tank. The filter was designed with such an objective that the drinking water standards have to be met. A prototype of the filter device was fabricated and used for laboratory studies on hydraulic efficiency and quality improving efficiencies.

Vertical flow filter system set up

The vertical flow roof water filter was also designed by using the first order kinetic (k - C*) model (Wong et al. 2006). A cylindrical column shaped filter made up of stainless steel was fabricated. It resembled a real-time prototype of column used for filtration studies (Fig. 1). The total Surface area of the filter, A_f was calculated as 0.125 m^2 and Fig. 2 shows the designed dimensions of the filter.

Fig. 1: Roofwater vertical flow filter.

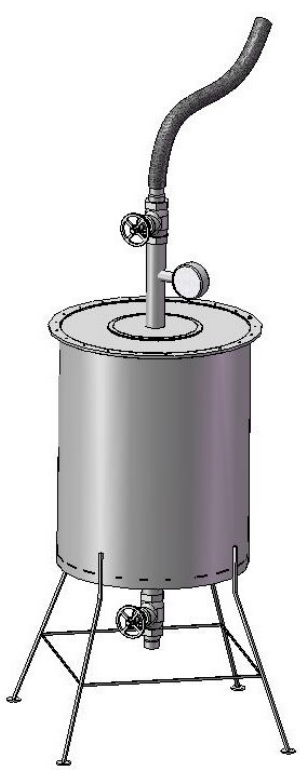
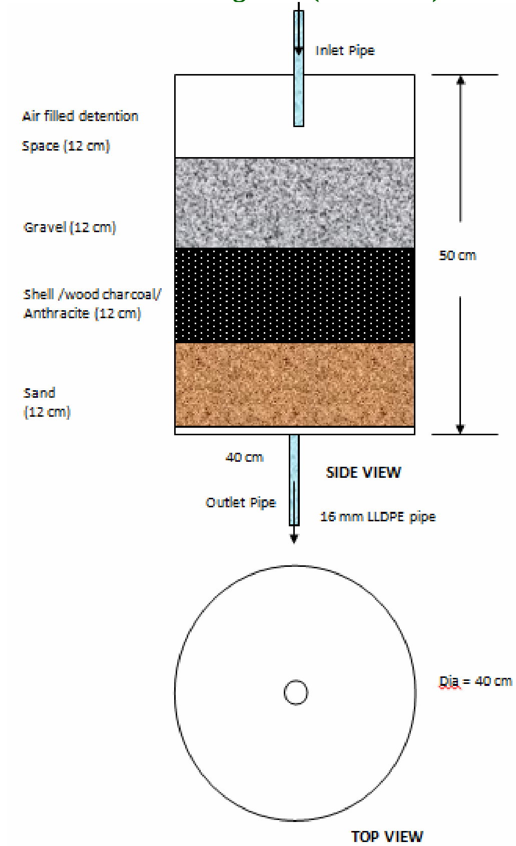


Fig. 2: Plan and elevation of roofwater filter with sand, charcoal and gravel (1:1:1ratio).



Polythene tubes of 16 mm size (4 kg cm^{-2}) were used as both inlet and outlet pipes. Two gate valves were fixed, one at the inlet and other at the outlet to regulate the flow of water. A precision pressure gauge was fixed in the inlet pipe just before the filter to observe the hydraulic head. Similarly, a U-tube manometer is fitted in the outlet pipe as shown in Fig. 3. Filer inlet was connected to pump and outlet to water sump by means of 16 mm size LLDPE pipes. Water was stored in a 500 litre capacity plastic tank (Sintex) and a 0.125 HP self-priming centrifugal pump was used to pump water from the sump towards the cylindrical filter. Rate of inflow was controlled by using a gate valve and pressure head of pumped water was measured using the precision pressure gauge, both attached to the inlet line. A u-tube manometer was fixed for a few experiments to measure hydraulic head of the outflow. The experimental set up is shown in Fig. 3.

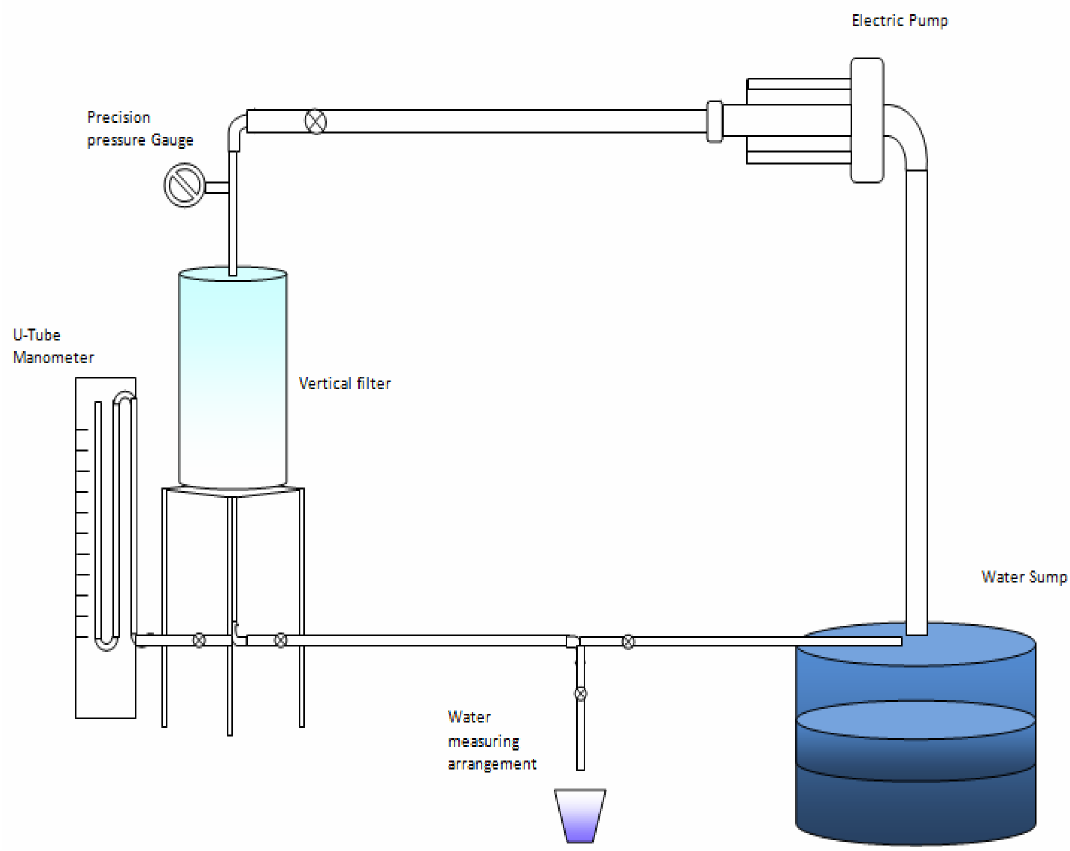
Filter media and screens

The filter under testing was a multi-media, vertical flow filter with three layers of filter materials separated by screens or without screens. Sand with mean particle size of 0.7 mm and uniformity coefficient 1.46 and crushed granite stones with average size of 20 mm were the generic media used and they were filled in the filter as the bottom and upper layers, respectively.

Three types of adsorbents, *viz.*, (coconut) shell charcoal, wood charcoal and anthracite, were tested as the middle layer. The sand and gravel were procured from the local market while the shell charcoal and wood charcoal were obtained by burning coconut (*Cocos nucifera*) shells and Prosopis (*Prosopis juliflora*) tree wood respectively. Apart from these, three types of circular shaped screens such as nylon, aluminum and non-woven coir-sisal fabric screens were also tested for its efficacy in removing pollutants in tandem with the filter media. The tests were also repeated with no screens.

Sand medium was filled first to the required height, and subsequently circular screen was inserted. The second layer is then filled to the required height, and again a screen was inserted and finally the upper layer was filled with gravel. The filter media were filled in four different volume ratios, viz., 1:1:1, 3:2:1, 2:1:3 and 1:3:2.

Fig. 3: Experimental set-up of vertical roofwater filter.



Design of experiment

Experiment was carried out in completely randomized factorial design (factorial CRD) and each treatment was replicated three times. The factors and levels of the second trial are depicted in Table 1.

The statistical analysis of variance was conducted as per the standard procedures. Difference between treatment means were tested for significance using standard analysis of variance tests. Subsequently Duncan's new multiple range test was employed for comparing the treatments.

Experimental measurements and analyses

Hydraulic efficiency (HE) is the measure of the fraction of the incoming stream that penetrates through the filter (Martinson and Thomas 2003). The rate of inflow and outflow were measured in three replications, and subsequently the amounts of water penetrated through and spilled over the filter were calculated.

Table 1. Factors and levels of second trial.

Filter Media	Screens	Proportions
Gravel- Charcoal (Coconut shell)-Sand (GCsS) *(M1)*	Non-Woven Sisal Coir (NWSC) *(S1)*	1 : 1 : 1 *(P1)*
Gravel- Charcoal (Wood)-Sand (GCwS) *(M2)*	Aluminum mesh *(S2)*	3 : 1 : 2 *(P2)*
Gravel-Anthracite-Sand (GCS) *(M3)*	Nylon *(S3)*	1 : 2 : 3 *(P3)*
	No screen *(S4)*	2 : 3 : 1 *(P4)*

The filter effectiveness or chemical removal efficiency can be expressed as the fraction of total chemical particulates removed by the filter (Hamoda et al. 2004). The same types of formulae were used for finding out the EC reducing efficiency and sediment removal efficiency. However since the pH has to be brought to the neutral value 7 by the filtration process, a new equation was formulated to find out the pH normalizing efficiency, as given below:

$$\text{pH normalizing efficiency} = p\left[\frac{pHi-|7-pHo|}{pHi}\right]100 \quad \ldots(1)$$

Where,
pH_i = initial pH of water before filtration.
pH_o = pH of water after filtration.

The term filter effectiveness was used in this paper as the mean of the removal efficiency values with respect to all analyzed physicochemical parameters and the pH normalizing efficiency and it is identical to the overall quality improving efficiency (QIE), which is referred in the following text.

Universal Performance Index

The UPI (Universal Performance Index) is new terminology introduced, and it is the weighted average of the hydraulic efficiency and quality improving efficiencies, giving extra weight to the latter. The UPI can be calculated as follows:

$$\text{UPI} = \frac{1}{2(n+1)}[\text{HE} + 2*\textstyle\sum_{i=1}^{i=n} QIEi] \quad \ldots(2)$$

Where,
HE = hydraulic efficiency.
QIE_i = quality improvement efficiency with respect to i^{th} parameter.
n = total no of chemical parameters tested.

The rate of inflow and outflow were measured by using a measuring cylinder and a stop watch. The inlet and outlet pressure heads were noted using precision pressure gauges fixed both in inlet and outlet pipes. The filtered water samples were collected as per standard methods in plastic containers and subjected to detailed water quality analysis for various chemical parameters using standard methods (APHA, AWWA and WEF, 2005; Saxena, 1994). The hydraulic efficiency, water quality improving efficiency and universal performance index (UPI) of various types of filter combinations were also computed.

Field evaluation of the best recharge filter combination, selected by laboratory experiments, was conducted at the PFDC farm of Department of Soil and Water Conservation, Tamil Nadu Agricultural University, Coimbatore (India). Apart from these, cost-benefit analyses were carried out for different types of filtration mechanisms. Along with the B-C ratio, net present value (NPV) and internal rate of return (IRR) were also computed using standard methods.

Results and discussion

The objective of roof water filter is to provide potable quality water by filtering water flowing down from rooftops. In this study, a vertical flow filter was developed for the purpose. Quantitative and qualitative performance of the roofwater vertical flow filter was carried out. The efficacy of three filter media combinations, viz., gravel- charcoal (coconut shell) - sand, gravel- charcoal (wood) - sand and gravel - anthracite - sand; three screens (non-woven sisal coir screen, aluminum mesh and nylon net) with no screens and four proportions (1:1:1, 3:1:2, 1:2:3 and 2:3:1) along with their 2-way and 3-way interaction effects were studied.

Hydraulic efficiency

Variation of hydraulic efficiency of the filter with respect to various proportions, media and screens were studied. It could be concluded that proportion P1 (1:1:1), media M3 (anthracite) and screen S2 (aluminum mesh) performed the superior based on its hydraulic efficiency. The filter combination P1M1S1 (gravel, charcoal (coconut shell) and sand in 1:1:1 proportion separated by non-woven sisal coir screens) showed the highest permeability apart from no screen combinations P1M1S4 and P3M2S4. The results of the ANOVA for finding out the variance among the effects and their interactions along with ranking based on the comparison of treatments using Duncan's MRT method is shown in Table 2.

The hydraulic performance of the superior four filter combinations (with screens), which exhibited higher hydraulic efficiency, against the control (without screens) is shown in Fig. 4. As expected, the combination P1M1S4 (no screens) showed reasonably higher hydraulic efficiency even at higher flow rates. The filter systems with screens exhibited higher hydraulic efficiency at lower flow rates, which decreased sharply till the flow rates reached above 0.16 L s^{-1}.

Table 2. ANOVA table of HE values of vertical flow filter at inflow rate of 0.1 L s^{-1}

Effect	Source of Variation	Hydraulic Efficiency – Vertical flow filters				
		SS	DF	MS	F	Best Rank (mean comparison by Duncan's MRT)
Main Effects	Proportion (P)	48632.5837	3	1034.7358	310.99**	P1>P3>P4>P2
	Media (M)	5171.7685	2	1723.9228	518.12**	M3>M2>M1
	Screens (S)	3511.5874	3	1755.7937	527.70**	S4>S2>S1>S3
2 way Interactions	Proportion/ Media	23182.8831	6	7727.6277	2322.52**	P1M3>P1M1>P3M3
	Proportion / Screens	4703.2865	9	783.8811	235.59**	P3S4>P1S4>P4S4
	Media /Screens	4246.8050	6	471.8672	141.82**	M3S4>M2S4>M1S4
3- way Interactions	Proportion/ Media/Screens	2717.4195	18	452.9032	136.12**	P1M1S4> P3M2S4> P1M1S1
Residual		319.4172	96	283.2685		
Total		48952.0009	143			
**Significant at 1 % level; C.V. (Treatment): 4.76%; SED: 0.33072; CD (0.01): 0.86916						

The best filter combination with screens, P1M1S1 was subjected to further hydraulic testing including sensitivity analysis. Fig. 5 shows the variability in hydraulic performance of the selected best filter with different media keeping the screen (non-woven sisal coir) and proportion (1:1:1) constant. It was observed that the media shell charcoal and anthracite performed well compared to the other media (wood charcoal) as far as hydraulic performance is concerned.

Fig. 4: Hydraulic performance of selected vertical flow roofwater filters.

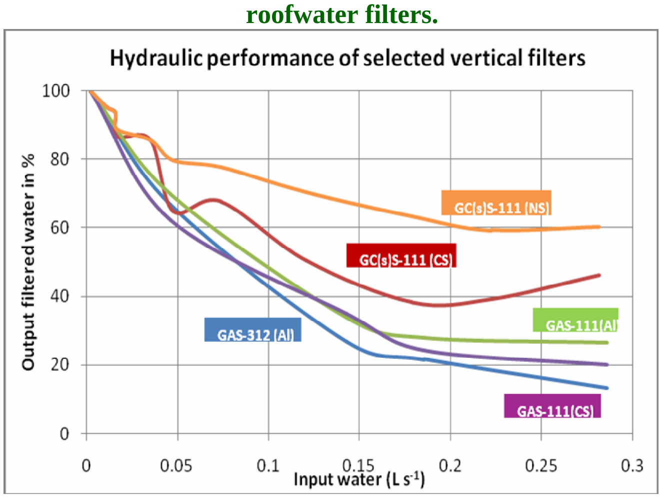
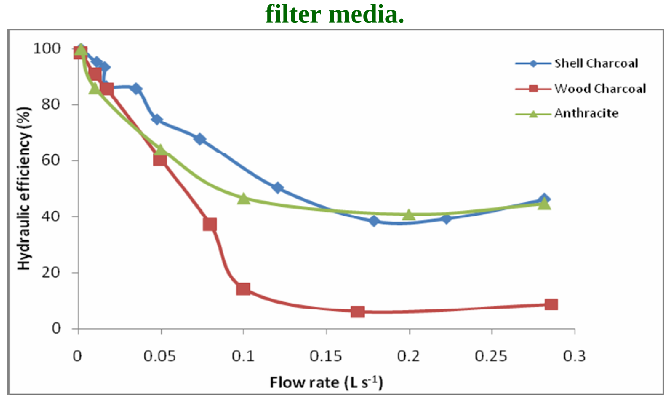


Fig. 5: Sensitivity of hydraulic efficiency with different filter media.



At very low flow rates, all media performed equally good, but the permeability of wood charcoal declined sharply and attained a constant rate when the flow rate was >0.1 L s^{-1}. The sharp decline might be due to blockage of filter screens by big blocks of wood charcoal in that particular case.

The coir-sisal non-woven fabric showed higher conductivity compared to other screens (Fig. 6). It might be due to a larger number of micro-pores as well as openings/cracks in the filter screen. The proportion 1:1:1 showed higher permeability than other three proportions tested (Fig. 7). The behavior of gravel-charcoal-sand filters with respect to its hydraulic properties resembled the results put forwarded by Martinson and Thomas (2005) based on a study of low-cost inlet filters for rainwater tanks.

Fig. 6: Sensitivity of hydraulic efficiency with different filter screens.

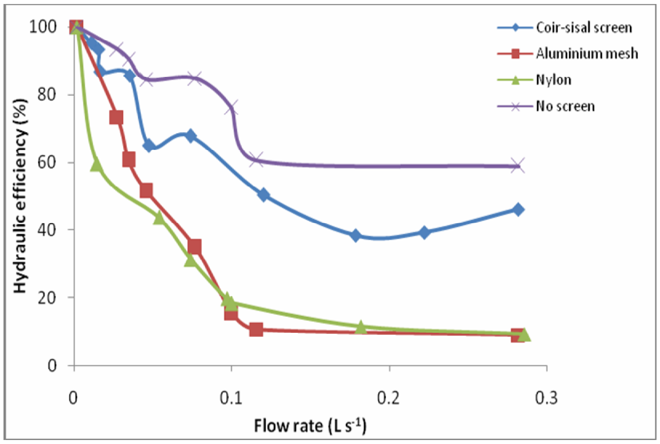
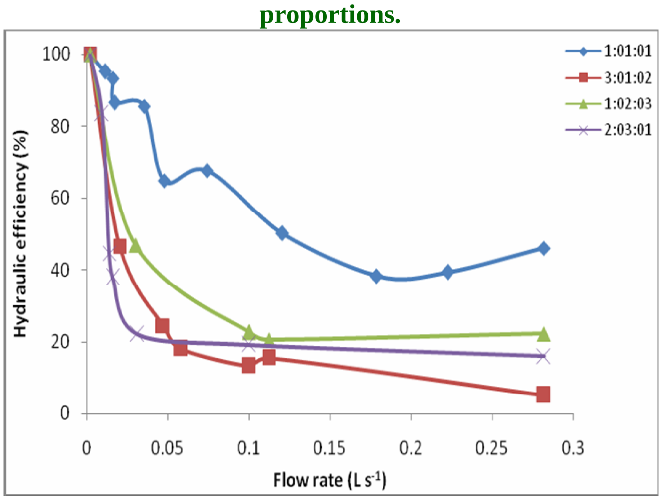


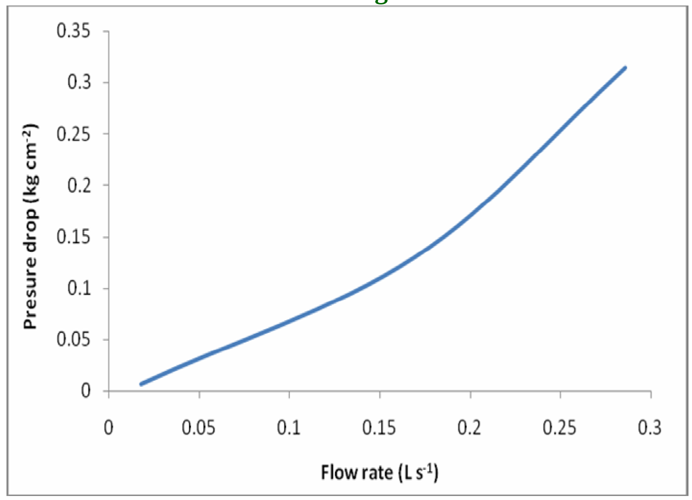
Fig. 7: Sensitivity of hydraulic efficiency with different proportions.



Hydraulic efficiency of the filter decreases non-linearly with increase in inflow volume. It is suggested from the results that water flowing through the filter would reach a maximum value and would not increase with further increase in inflow. The findings are similar to those of Hatt et al. (2009).

The relationship between pressure drop (head loss) and rate of flow through the filter was also studied (Fig. 8). The experiment was conducted with the selected best filter combination at various flow rates. It is clear from the graph that the rates of flow and head losses were linearly proportional to each other.

Fig. 8: Relationship between pressure drop (head loss) and rate of flow through the filter.



Quality improving efficiencies

The quality improving efficiencies of all 48 filter combinations were determined (Table 3). The multi-layered, multi-media, vertical filters were found to be highly effective in removing TS, K^+ and PO_4^{2-}. The filter was excellent in normalizing the pH and reducing the EC. It also exhibited fairly good efficiency in removing NO_3^-. The removal percentage of iron (Fe^{2+}) and sodium (Na^+) were comparatively low at 17.36 % and 14.34 % respectively. However, it was observed that the calcium (Ca^{2+}) removal was negligibly less, and the magnesium (Mg^{2+}) concentration was getting increased after filtration and this might be due to the effect of charcoal.

Areerachakul et al. (2009) reported a reduction of nitrate and phosphate at 80 %and 30 %, respectively, in the 10-cm filter bed depth of granular activated carbon (GAC) filter with a submerged membrane system. However, Rasima et al. (2009), based on a study of multimedia filtration that consist of granular activated carbon - biofilm configured up-flow fluidized expanded bed (UFEB) reactor, reported 75.49 % removal of iron (Fe^{2+}) and 51.76 % to 82.98 % removal of NO_3^-. In the present study, phosphate removal was recorded high (98 %) compared to nitrate (44 %). It could be concluded from the study that sand-charcoal-gravel roof water filters were very good for removing chemicals such as K^+, Na^+, PO_4^{2-} and NO_3^-, but they were not recommended for removing Ca^{2+} and Mg^{2+}. It was also observed that the three significantly different activated carbon materials (shell charcoal, wood charcoal and anthracite) gave minor differences in adsorption.

Table 3. Average removal efficiencies of chemical parameters in roofwater by vertical flow filters.

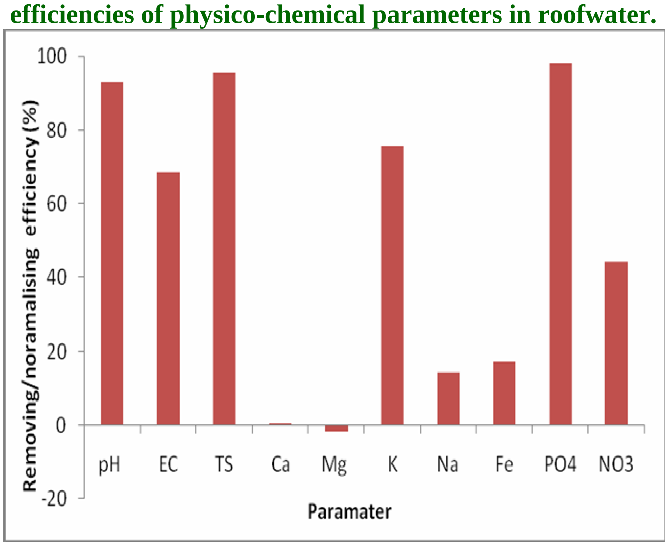
Parameter		pH	EC	TS	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Fe^{+}	PO_4^{2-}	NO_3^{-}
Average Removal Efficiency (%)		93.17	68.47	95.69	0.66	-1.77	75.56	14.34	17.36	98.12	44.12
Standard Deviation		1.755	12.4	4.53	11.90	7.376	10.45	19.53	49.94	1.25	2.22
Range	Max	96.82	78.66	100	16.33	3.970	85.9	32.35	97.98	99.93	64.43
	Min	88.64	34.45	87.03	-31.6	-20.78	53.85	-35.29	-74.24	95.66	23.81

Table 4. ANOVA table of QIE values of vertical flow filter at inflow rate of 0.1 L s^{-1}.

Effect	Source of Variation	Quality Improvement Efficiency – Vertical flow filters				
		SS	DF	MS	F	Best Rank (mean comparison by Duncan's MRT)
Main Effects	Proportion (P)	554.282	3	184.761	49.72**	P3>P4>P2>P1
	Media (M)	117.228	2	58.614	15.77**	M3>M1>M2
	Screens (S)	5449.695	3	1816.565	488.89**	S2>S1>S3>S4
2 way Interactions	Proportion/Media	313.429	6	52.2386	14.06**	P3M1>P4M3>P4M2
	Proportion /Screens	482.5409	9	53.616	14.43**	P4S2>P1S2>P3S2>
	Media /Screens	236.0819	6	39.347	10.59**	M3S2>M1S2>M2S2
3- way Interactions	Proportion/Media/ Screens	326.438	18	18.135	42.83**	P4M3S2>P4M2S2> P2M3S2
Residual		7479.693	96	159.142		
Total		356.70883	143	3.716		
**Significant at 1 % level; C.V. (Treatment): 4.45%; SED: 0.45434; CD (0.01): 1.19404						

The average filter performance efficiency with respect to removing/ normalizing various physicochemical parameters in roof water is depicted in Fig. 9. The results of quality analysis were subjected to ANOVA and presented in Table 4. The best media, screen, proportion and combination were delineated based on Duncan's MRT method as shown in the table.

Fig. 9: Average percentage removal/normalizing efficiencies of physico-chemical parameters in roofwater.



The regression equations developed for sediment reduction capacity (Eqn. 3) and overall chemical removal efficiency (Eqn. 4) of the vertical filter are:

$$S_{out} = 0.1282\ S_{in} - 0.2706 \quad \ldots(3)$$
$(R^2 = 0.9646)$

$$C_{out} = 0.8982\ C_{in} - 5.3274 \quad \ldots(4)$$
$(R^2 = 0.9358)$

Where,
S_{in} and S_{out} are TS load in inlet and outlet water respectively;
C_{in} and C_{out} are the chemical concentrations in inlet and outlet water respectively.

Universal Performance Index

The UPI values of each filter combinations were computed and subjected to analysis of variance. The results of ANOVA are presented in Table 5. The significance value comparing the groups is <0.01, so the null hypothesis, that there is no difference in the mean UPI values with the three major effects and their interactions, was rejected. The best media, screen, proportion and combination were delineated based on mean comparison by Duncan's MRT method as shown in Table 5.

Table 5. ANOVA table of UPI values of vertical flow filter at inflow rate of 0.1 L s^{-1}.

Effect	Source of Variation	Universal Performance Index – Vertical flow filters				
		SS	DF	MS	F	Best Rank (mean comparison by Duncan's MRT)
Main Effects	Proportion (P)	239.649	3	50.660	31.07**	P3>P1>P4>P2
	Media (M)	256.038	2	79.883	49.00**	M3>M1>M2
	Screens (S)	933.237	3	128.019	78.52**	S2>S1>S4>S3
2- way Interactions	Proportion/Media	281.172	6	311.079	190.81**	P1M3>P3M1>P3M3
	Proportion / Screens	351.538	9	46.862	28.74**	P3S4> P3S2> P1S2
	Media /Screens	115.322	6	39.06	23.96**	M3S2>M2S2>M3S1
3- way Interactions	Proportion/ Media/ Screens	204.081	18	19.220	11.79**	P1M3S2>P2M3S2> P1M3S1
Residual		156.510	96	11.338		
Total		2537.543	143			

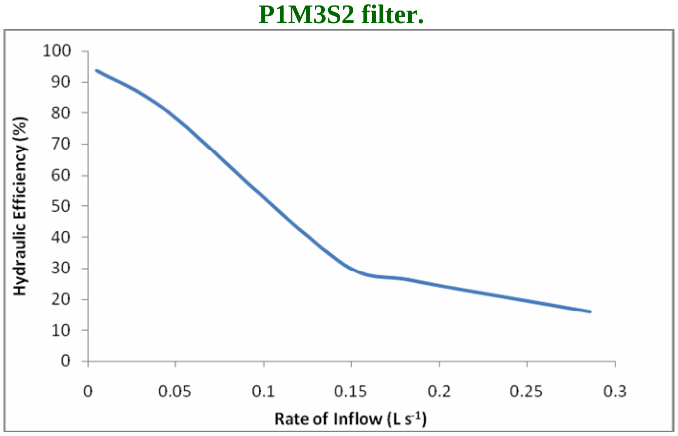
**Significant at 1 % level; C.V. (Treatment): 4.40%; SED: 0.30095; CD (0.01): 0.79092

Table 6. The cost of filtration, NPV, IRR and BCR values of roof water filtration system.

Type of filter	Cost of filtration/m^3(₹)	NPV (₹)	IRR (%)	BC ratio
Roofwater	17.75	345.64	22	1.07

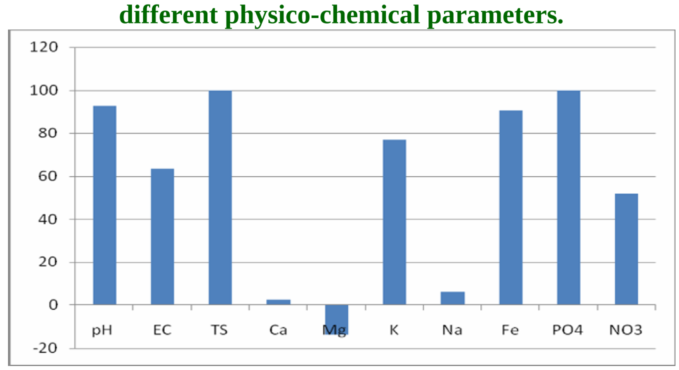
All individual effects and their interactions were found to be significant at 1 % level. Based on comparison of mean of the universal performance indices by Duncan's MRT method, the proportion P3 (1:2:3), media M3 (anthracite) and screen S2 (aluminum mesh) were found to be the best considering the overall ratings. As far as superiority in filter combination is concerned, P1M3S2 (gravel-anthracite-sand in 1:1:1 proportion separated by aluminum meshes) emerged the best.

Fig. 10: Effect of rate of inflow on hydraulic efficiency of P1M3S2 filter.



Effect of flow rate on hydraulic efficiency for the P1M3S2 filter is shown in Fig. 10. The hydraulic efficiency was found higher at lower flow rates. The removal efficiency of the P1M3S2 filter for different parameters is depicted in Fig. 11. The filter was found very well in removing TS, PO_4^{2-}, Fe^{2+}, K+ and reducing EC. It was also good in normalizing the pH. But removal efficiency of Ca^{2+} and Na^+ were too less, while that of Mg^{2+} was negative.

Fig. 11: Removal efficiency of the P1M3S2 filter for different physico-chemical parameters.



Economic analysis

The cost of filtration per cubic meter of water, net present value (NPV), internal rate of return (IRR) and benefit-cost ratio (BCR) for roof water filter were computed and presented in Table 6. The developed filtration systems are recommended from an economic point of view being a low-cost technology requiring low initial expenditure, zero power need, no maintenance cost and self-dependent operation. They are suitable for areas where there are normal seasonal rains. It was also inferred that the natural fibre filter screens along with other filter media used in this study are essentially bio-degradable and environmentally friendly in nature.

Conclusions

A vertical flow filtration mechanism was designed, developed and evaluated for filtering roof water. The designed diameter and height were 0.4 m and 0.5 m, respectively. Variation of hydraulic efficiency of the filter with respect to various proportions, media and screens were studied and proportion P1 (1:1:1), media M3 (anthracite) and screen S2 (Aluminium mesh) were found superior. Sensitivity of hydraulic efficiency with different media, screens and proportions were studied. Study on the relationship between pressure drop (head loss) and rate of flow through the filter revealed that the flow rate and head losses were linearly proportional to each other. The roof water vertical filters were found to be highly effective in removing TS, K and PO_4^{2-}, normalizing pH and reducing EC. It had fairly good efficiency in removing NO_3^-. The removal percentage of Fe^{2+}, Na^+ and Ca^{2+} were low, while that of Mg^{2+} showed –ve value.

ANOVA of UPI values for roof water filters showed that all individual effects and their interactions were significant at 1% level. Based on the comparison of mean, the proportion P3 (1:2:3), media M3 (anthracite) and screen S2 (Aluminium mesh) were found to be the best. P1M3S2 (gravel-anthracite-sand in 1:1:1 proportion separated by Aluminium meshes) emerged the best filter combination. Effect of flow rate on hydraulic efficiency for the P1M3S2 filter showed higher efficiency at lower flow rates. The filter was found very well in removing TS, PO_4^{2-}, Fe^{2+}, K^+ and reducing EC. But removal efficiency of Ca^{2+} and Na^+ were too less, while that of Mg^{2+} negative.

Based on the estimated annual costs and returns, all the financial viability criteria (IRR, NPV and BCR) are found favourable and affordable by farmers for investment on developed roof water filtration system. The natural fibre filter screens used in this study were cheap, environmentally compatible and biodegradable. The other filter media were also commonly available and renewable in nature.

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