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Development of a cost-effective activated carbon incorporated sand gravel filter for rainwater treatment

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ABSTRACT

Drought-related water stress conditions are prevailing in the country due to the rainfall variability and pollution of water sources by agrochemicals. Roof Rainwater Harvesting Systems (RRHS) are promising solutions to address the increasing demand for drinking water, especially in drought-stricken areas. However, RRHS is not popularized among most communities mainly due to suspicion of rainwater quality. Thus, the present study focuses on assessing the efficiency of a simple, slow sand filtration system integrated with an activated carbon layer for rainwater treatment. The sand gravel filter was developed cooperating with a Corn cob-based activated carbon layer. The filter includes fine sand, activated charcoal, coarse sand, and gravel from top to bottom. Rainwater samples were collected from five locations using the storage vessels of RRHS in the Medawachchiya area in the Anuradhapura district. Harvested rainwater was analyzed using the standards methods (APHA). Physio-chemical and microbiological parameters of water were measured before and after the treatment through the activated carbon incorporated sand-gravel filter. The results showed that the filter removed 99.9% and 95.5 % of faecal and total coliform in rainwater samples. Turbidity, nitrate, and nitrite concentrations were reduced by 83.1%, 82.9%, and 90.7%. pH, Total Dissolved Solids (TDS), Electrical Conductivity (EC), Chloride, Sulphate, Total Hardness (TH), Total alkalinity (TA) and free Ammonia have been reduced by 7.6%, 34.5%, 34.9%, 49.1%, 12.5%, 51.1%, 57.2%, and 33.7% respectively after passing through the filter. Color, free iron, and residual chlorine of stored rainwater were under the Sri Lanka Standard Institute (SLSI) accepted range before passing through the filter. Therefore, the present study results showed that the activated carbon incorporated sand filters to the RRHS could be recommended as a sustainable solution to upgrade the drinking water quality of harvested rainwater.

KEYWORDS: *Sand gravel filter, Activated carbon, Roof Rainwater Harvesting Systems (RRHS), Water quality*

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1 INTRODUCTION

Roof rainwater is a good source of potable and non-potable water, which could be used for all domestic activities, including the drinking water requirement (Ariyananda *et al*., 2013). Approximately 80% of households use rainwater to fulfil their drinking needs in tsunami resettlement areas of the southern province, as recorded by Aheeyar and Ariyananda (2014). However, most local consumers are reluctant to use the Rain Water Harvesting (RWH) technique due to hygienic issues. One of the reasons for the non-acceptability of rainwater for drinking purposes is consumers' negative attitudes toward the quality of harvested rainwater (Ariyananda, 2003).

The most common hazard in water sources obtained from roof catchments is microbial contamination, especially the enteric pathogens that cause gastrointestinal illness and cause a risk to human health (Ariyananda, 2005). Theoretically, rainwater is relatively free from impurities but becomes contaminated by atmospheric pollutants during precipitation. In general, the presence and the concentrations of organic, inorganic, physical, and biological impurities depend on several factors, such as roof characteristics, meteorological factors, location of the roof, hydrological aspects, chemical properties of the substance, and storage material (Meera and Ahammed, 2006; Despins *et al*., 2009). The parameter of utmost concern in harvested rainwater is the presence of microbial pathogens, particularly the faecal bacteria present in animal droppings. The collected rainwater could risk human health if consumed untreated (Ahmed *et al*., 2008, 2011).

The current status of RWH in the Anuradhapura district in Sri Lanka shows that 38% of RWH systems are not under operation (Ariyananda, 2003). However, a substantial percentage of domestic rainwater system owners were reluctant to use rainwater for drinking due to false perceptions and the lack of awareness about the water quality and security of the RWH (Bandara *et al*., 2006). The main reasons for not using rainwater were lack of filter in the system, the presence of alternative sources, and the perception of rainwater being unclean (Strand, 2013). According to the community perception analysis by Bandara *et al*. (2006), more than 50% of the rainwater harvesters were not using filters and first flush systems. Therefore, it was identified that the effectiveness of current RWH systems could be further improved if they incorporated a filter system into their domestic RWH systems.

Therefore all rainwater tanks must be fitted with proper structural devices like filter and first flush system and simple treatments like boiling to improve the biological quality of water up to the standards (Strand, 2013). Many RWH systems used for drinking water rely on sediment filters, carbon filters, and ultraviolet (UV) light to remove all harmful impurities and ensure the water is potable. This standard water purification system has proven effective for decades; however, it is not equally effective in all scenarios.

Activated carbon is an excellent adsorbent and thus is used to purify, decolorize, deodorize, de-toxicate, filter or remove the contaminants (Idroos and Manage, 2016). Activated carbon filters have been used to treat water's odor and taste problems for a long time. Today, they are used in millions of residential and commercial-grade systems. Activated carbon has been proven to be an excellent method of producing better-tasting water and removing harmful water contaminants. Thus, the present study focuses on developing an activated carbon incorporated sand filter as an effective rainwater treatment device to improve the effectiveness of RWH techniques.

The filtration process consists of a combination of physical and chemical processes that enable the removal of suspended and colloidal particles and microorganisms present in the water that flows through a porous medium, also called a filtration medium. Sand water filters effectively retain solid matter in suspensions, such as algae, other organic matter, and fine sand and silt particles. The better ability of a sand filter to remove organic matter when compared to different types of filters is because contaminants are collected as the water passes through the sand layer.

The development of a filtration system with sand and activated carbon for rainwater treatment in Malaysia was investigated by Shaheed *et al*. (2017). In this study, the activated carbon was obtained from coconut shells of local origin. It was activated using readily available salt instead of a high-technology procedure requiring a chemical reagent. The system produced effluents that met the potable water standards for pH, dissolved oxygen (DO), Chemical Oxygen Demand (COD), TDS and *E.coli* population. Yan *et al*. (2018) presented a device for filtration treatment with activated carbon and disinfection by ozonation to obtain potable water from rainwater in England. The field tests showed that the device could reach this objective by reducing energy consumption.

Hence, this study endeavored to probe the effectiveness of a low-cost, self-prepared combined activated carbon and sand filtration system for roof-harvested rainwater. In exploring different sources to produce activated carbon, many natural sources have been used; coconut shells, peel of manioc, rice husks, corn cobs, etc. Many studies reported using activated carbon from-corn cobs to treat drinking water. Corn Cobs are suitable for preparing microporous activated carbon due to their excellent natural structure and low ash content (Deepa *et al*., 2015). Any cheap material with high carbon content, and low inorganics can be used as a raw material for the production of activated carbon, and Tsai *et al*. (1997) used corn cobs to produce activated carbon, followed by chemical activation using Zinc chloride. The present study also focused on utilizing corn cobs to produce activated carbon, as this is a naturally available source in the dry zone of Sri Lanka.

2 MATERIALS AND METHODS

2.1 Collection of rainwater samples

Rainwater samples were collected from five locations (W1-W5) from the storage vessels of the roof rainwater harvesting systems (RRHS) within five Grama Niladhari (GN) divisions of Madawachchiya of Anuradhapura district, which belongs to the dry zone. pH (EUTECH ™ - 800658 pH meter), free ammonia (using LOVIBOND ammonia tablets), color (LOVIBOND PHOTOMETER-MAXIDIRECT), EC (HACH Hq-40 D, 130 3000086458), TDS (TDS Meter-LOVIBOND 1540535) and Turbidity (EUTECH TN -100- 347700 turbidity meter) of collected water samples were measured following the standard protocols using the standard meters. Free iron, Nitrite, Nitrate, Chloride, Salinity, Sulfate, TH, and TA and Microbiological parameter; Faecal Coliforms (FC) and Total Coliforms (TC) numbers were recorded following the standard protocol (APHA, 2017). These parameters were measured before and after the treatment using the activated carbon incorporated sand filter.

2.2 Preparation of activated carbon for sand filter

Corn cobs were used as the raw material for the preparation of charcoal. Fresh charcoal was prepared according to the procedure given by Deepa *et al*. (2015). Pure corn cobs were collected and sun-dried to remove the moisture content. Subsequently, the corn cobs were oven-dried for 2 hours and 30 minutes until the complete removal of moisture. Next, they were crushed using a mortar and pestle and sieved to obtain a particle size of 0.425 – 1 mm.

2.3 Preparation of activated carbon

Charcoal was subjected to chemical activation to prepare activated carbon according to the method given by Verla *et al.* (2012). Zinc Chloride (25 % w/w) was used to treat the prepared carbon, and carbon was soaked in $ZnCl_2$ for 18 hours in a fume hood to remove gas and impurities. Subsequently, it was heated at 110 °C for 12 hours in a hot box oven (OHG097. XX1.5) and carbonized at 500 °C for 3 hours in an inert environment of a muffle furnace LVT/11(LIFT DOOR) GERMAN. Finally, charcoal was washed with sterilized distilled water and heated at 110 °C for 12 hours in the hot box oven. The prepared charcoal is presented in Fig 1.

Fig 1. Sieved activated carbon (0.425 – 1mm)

2.4 Development of a laboratory-scale sand filter to treat harvested rainwater

The experimental setup consisted of sand filter columns amidst a prepared activated carbon layer. The fine sand layer (12cm) outlined the activated carbon layer, while the activated carbon, and coarse sand gravel layers were maintained at 5cm for each layer. An outflow weir controlled the minimum supernatant water level. The flow rate was maintained at 0.4 $Lmin^{-1}$ using valves set up to the sand filter column. A minimum supernatant level of 10 cm was maintained above the sand bed. Filter design, material, and operating conditions are listed in Table 1.

Fig 2 presents the developed sand filter. Sand and gravel used for the experiment were washed in distilled water and autoclaved at 121^0C for 15 minutes at 1.5 atm. Then they were dried in an oven at 100 ^{0}C for 40 minutes before introducing the sand filter column.

Table 1. Filter design, material, and operating conditions of the sand filter column

Components	Size (mm)	Depth (cm)
Fine Sand	0.125- 0.425	12
Coarse sand	2-4	5
Gravel	4-8	5

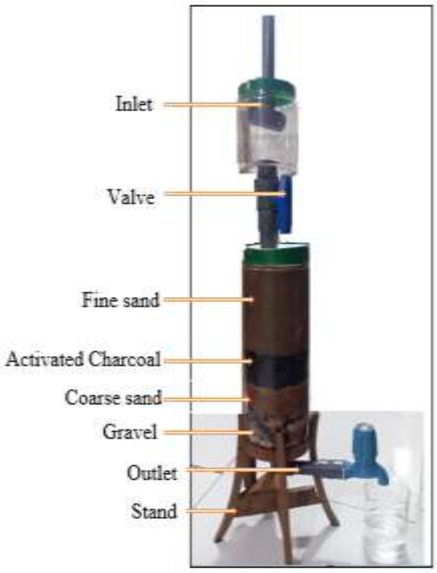


Figure 2. Sand filter with activated carbon

3 RESULTS & DISCUSSION

Many studies on harvested rainwater quality have shown that pH, total Chlorine concentration, EC, TDS, Oxygen saturation present and TH remained within WHO standards, except for the TC count, which usually is moderate to high based on maintenance of the collector surface (Sendanayke, 2016). Therefore, adopting activated carbon incorporated sand filters to the RWH system at the outlets would be an excellent solution to improve the quality of stored rainwater. Table 2 presents the physico-chemical parameters of rainwater before and after treatment through the developed sand filter.

Table 2. Physico-chemical parameters of water samples before and after the treatment through the developed sand filter

Parameter	**W1**	**W2**	**W3**	**W4**	**W5**	**W1**	**W2**	**W3**	**W4**	**W5**
	Before the treatment					**After the treatment**				
pH	8.36	7.9	7.5	8.12	8.1	7.25	7.3	7.1	7.425	7.82
Turbidity (NTU)	6.8	5.2	0.9	10.2	4.1	0.8	0.5	0.35	1.8	0.26
Free Ammonia (mg/L)	0.049	0.037	0.073	0.024	0.061	0.037	0.024	0.037	0.024	0.024
Nitrite (mg/L)	0.16	0.05	0.06	0.30	0.01	0.00	0.00	0.00	0.06	0.00
Nitrate (mg/L)	4.13	2.72	3.41	4.69	1.27	1.16	0.02	1.27	0.55	0.10
Chloride (mg/L)	146.0	16.8	15.6	8.0	16.0	46.0	12.0	10.0	4.0	6.0
Sulphate (mg/L)	10.8	9.7	9.2	17.4	9.7	9.5	9.3	9.1	10.9	9.0
Total Alkalinity (mg/L)	224	112	56	36	172	66	44	28	20	68
Total Hardness (mg/L)	124	76	32	88	116	88	40	16	32	40
Total Dissolved Solids mg/L)	110	200	40	20	80	80	160	25	10	50
Electric Conductivity (dS/m)	0.07	0.09	0.16	0.19	0.06	0.05	0.02	0.14	0.15	0.04
Color (Hazen units)	ND	56.5	ND	ND	ND	ND	ND	ND	ND	ND
Free Iron (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Salinity (ppt)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

(ND- Not detected)

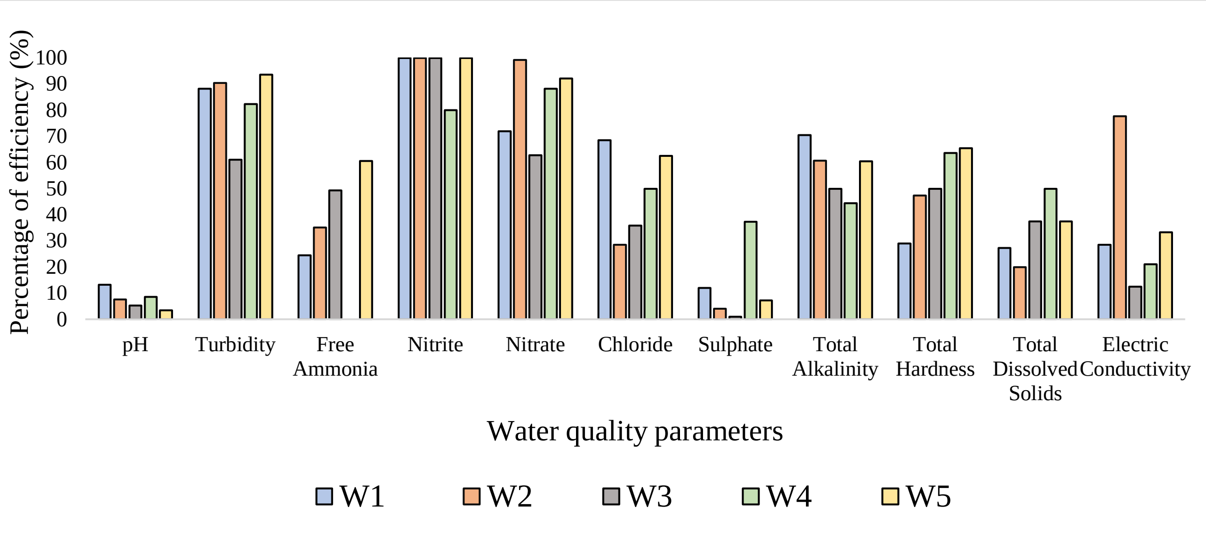


Figure 3. Treatment efficiency of the filter system for the collected rainwater samples

Treatment efficiency of the filter system for the collected rainwater samples from the W1, W2, W3, W4, and W5 locations are present in Fig 3. pH values of all five water samples showed a remarkable reduction following treatment through the developed sand filter. The highest pH reduction recorded in sample W1 was from 8.36 to 7.25 (13.3% reduction) following the treatment through the sand filter. However, the pH values of collected rainwater samples were within the SLS drinking water quality. All water samples except W3 showed turbidity above the standard value of 2 NTU before treatment. However, following the treatment, turbidity in samples; W1, W2, W3, W4, and W5 was reduced by less than 2 NTU. The highest turbidity reduction was recorded in W4, which was 82.3%.

Samples W3 and W5 had free Ammonia above the standard limit of 0.06 mg/L (Table 2). However, free ammonia concentration of samples W1, W2, W3, and W5 showed a reduction following the filter treatment, whereas, in sample W4, Ammonia concentration remained unchanged at 0.0024 mg/L. This may be due to low detectable levels of the method. The highest free Ammonia reduction was recorded in W3, which was 67.1%.

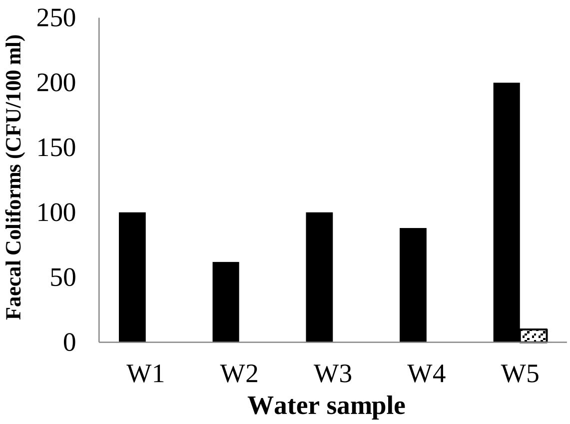
Before the treatment, nitrite concentrations of all five rainwater samples were recorded below the acceptable drinking water limit (3 mg/L). Following the treatment, all five samples showed a reduction in Nitrite concentrations, whilst the highest reduction percentage of 80 was recorded for sample W4. The highest reduction for nitrate after filtering was also recorded in sample W4, 82.4%.

The Chloride concentration in rainwater samples was decreased after the filtration. Chloride concentrations in all samples were recorded below the acceptable level of 250 mg/L before the treatment and further reduced after the treatment, with the highest reduction of 68.5% in sample W1. Sulphate concentrations in all water samples were within the standards (less than 250 mg/L) before passing through the filter. The highest sulphate reduction, 37.3 %, was found in sample W4.

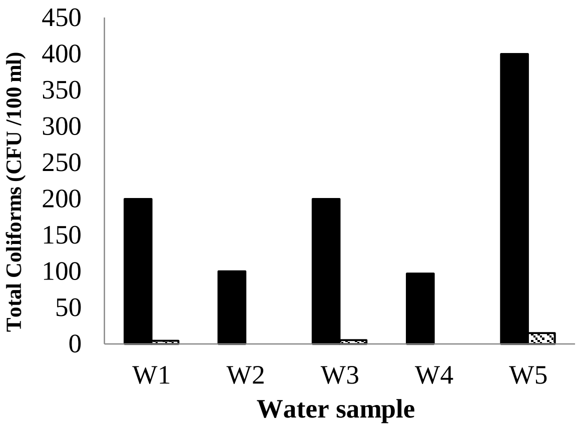
Total alkalinities were recorded below the acceptable limit of 200 mg/L in four samples except for sample W1 before the treatment. All samples showed a notable reduction following the treatment, while sample W1 showed a decrease of 70.5%. Total hardness in all five water samples was below the acceptable limit of 250 mg/L before the treatment and complied with drinking water standards. Sample W5 recorded the highest reduction of 65.5% hardness removal following the treatment. TDS content has been decreased in all five samples after the filtration process. TDS content was lower than the acceptable limit of 500 mg/L in all samples before the treatment, and a notable further reduction was observed after the treatment. In sample W2, the highest reduction of 20% was recorded.

The initial conductivity of rainwater was similarly reasonably low, and it has been further decreased after the filtration, with sample W2 showing the most significant reduction (77.8%). Before the treatment, the color in the W2 sample was above the acceptable limit of 15 Hazen units. All other samples were recorded as under-range values when measured from the LOVIBOND photometer. Following the filtration, the color of the sample W5 was reduced to an underage value. Before filtering, free iron was low in all rainwater samples before filtering and the values were obtained as under-range values when measured from the comparator (<0.01). The maximum acceptable requirement of free iron for potable water was 3 mg/L according to the SLS 614:2013. Salinity values were also recorded under range in all rainwater samples before treatment through the activated carbon incorporated sand filter.

However, it is noteworthy that the sand filter constructed by Adewumi *et al*. (2017) has recorded much lower treatment levels for rainwater. Adewumi *et al*. (2017) recorded 4% for pH, 58% for turbidity, 90% for Nitrate removal, 31.8% for Chloride and 37.5% for total hardness, 30% for TDS, 84% FOR Sulphate and 86% for EC. Although free iron was within the undetectable range in the present study, Adewumi *et al*. (2017) recorded 42% of iron removal.



(a)



(b)

Figure 4. The recorded number of (a) Faecal Coliforms, (b) Total Coliforms in water samples W1-W5 (Colored bars-Before the treatment, Hatched bars- after the treatment)

Fig 4 (a and b) represents the number of faecal coliforms (FC), and total coliforms (TC) recorded in the water sample before the treatment and after the treatment. Generally, the FC *E.coli* should not be present in the effluent, as strictly stipulated by the drinking water guidelines (MOH, 2000). In the present study, all rainwater samples recorded over 60 FC /100 ml of water before the treatment. However, following the treatment, no FC was detected except in sample W5, which was an average of 10 CFU/ 100 ml.

The analyzed rainwater samples exceeded the acceptable limit of less than 10 TC CFU/100 ml given by the SLSI standards (2013) for drinking water before the treatment. However, no TC was recorded following the treatment through the activated carbon filter except for sample W5, which was 9 CFU/100 ml (Fig. 4b). However, the TC numbers complied with Sri Lankan drinking water standards.

Further, studies were done by Yogafanny *et al*. (2014) on slow sand filtration in removing total coliforms, and *E.coli* showed that finer sand was more adhesive. Moreover, the sand surface area caused an increase in adsorption spots on the sand and, therefore, the biofilm attached to the sand grains. The present study showed that the filter achieved 97.7 – 99.99% removal of TC and 97.6 – 99.99% removal of FC bacteria.

Therefore, adopting activated carbon incorporated sand filters to the RWH system at the outlets can be recommended as an excellent solution to improve the quality of stored rainwater as microbial contamination has become a common issue resulting in the deterioration of rainwater quality. As a result, the overall effectiveness of the RWH filter should be improved.

4 CONCLUSIONS

This study investigated the performance of low-cost, activated carbon and sand filtration for rainwater treatment. Harvested rainwater was generally of good quality, except for FC and TC, which were significantly higher than the drinking water standard guidelines. Overall, the developed activated carbon sand filter treated the harvested rainwater and lake water to place it within the permissible limit set by the drinking water standard for all parameters, except the bacteria. The prepared activated carbon's performance was similar to that of commercially available activated carbon or high-tech bio-waste activated carbon. Hence, the present study has forwarded an effective solution to the Anuradhapura district's rainwater harvesters enabling effective utilization of harvested rainwater.

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