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Evaluating the efficacy of household filters used for the removal of bacterial contaminants from drinking water

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Due to the erratic nature of microbial contaminants in drinking water, private and municipality water supply systems failed to deliver safe drinking water to households. In Ethiopia, there is lack of data and knowledge on the effectiveness of filter devices used to treat drinking water at household. This study aims to evaluate efficiency of household point of use filter devices (membrane filter, membrane with activated carbon, ceramic candle type filter and hybrid (multistage)) in reducing bacterial contaminants from drinking water. Percent reduction efficiency model was employed in evaluating bacterial removal efficiency. Membrane filter and membrane with activated carbon filter devices had good total coliform removal efficiency on the 1st and 2nd days than hybrid filter device which showed low removal efficiency. Similarly, all filter devices showed better fecal coliform removal efficiency on the 1st day compared to 2nd day but had low heterotrophic bacteria removal efficiency during the three days filtration. Fecal *Streptococcus* removal efficiency on the 2nd and 3rd days by all filter devices was low except the first day. The result in general showed that using of point of use filter devices for prolonged time could not guarantee in providing risk free drinking water at household level.

Key words: Coliform, drinking water, household filters, point of use, removal efficiency.

INTRODUCTION

Contamination of drinking water by waterborne pathogens in piped water distribution systems, at storage facilities and at point of use is the most serious human health risk, causing outbreaks of different diseases. In Ethiopia, 56% of the urban population had access to piped water through centralized water treatment and piped distribution networks but majority of the rural population used untreated water from surface water sources (Usman et al., 2016). But quality of drinking water gets poorer in water distribution systems due to leakage through corrosion of pipes, intrusion of microbial contaminants and other physicochemical pollutants that causes diarrheal and other diseases (Dawit, 2015; Adane et al., 2017).

To avoid the risk of poor-quality water consumption, different point of use water treatment and filtration technologies with variable microbial and other contaminant removal effectiveness have been developed and introduced to users. In many low-income nations, point of use filter devices made from locally available materials and/or available with inexpensive prices from venders used commonly as an intervention for household water treatment solutions (Angela, 2011). World Health

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Organization (WHO) and United Nations Children's Fund (UNICEF) recommend and promote these filter devices for removing microbial and physicochemical contaminants and as general strategy for preventing water-borne diarrheal diseases in low income countries (WHO/UNICEF, 2017).

Household water treatment and safe storage (HWTS) technologies provide moderate levels of safe water supply at point of use. Household water treatment interventions are the most effective alternative at household level than at community level to reduce various contaminants at point of consumption since treated water delivered through distribution systems gets contamination between point of treatment and consumption in low-income nations (Anke et al., 2018).

Filtration mechanisms such as bio sand filter, solar disinfection, ceramic filtration, chlorination at point of use and combined flocculation/disinfection are the most practiced systems in Ethiopia. The most used point of use filtration systems at household level are mesh like clothing in rural areas, membrane, and ceramic filter devices in urban areas (Abrham et al., 2018b). Ceramic filter devices can be made from locally available materials, affordable and used by individuals for household point of use (Enyew and Tesfaye, 2017).

A case study in Eastern Ethiopia showed that point of use drinking water filtration devices are the most effective and recommended alternatives in removing several pollutants and water-borne pathogens and makes water safe for household consumption under proper usage (Abrham et al., 2018a). In Addis Ababa, membrane filtration devices, hybrid filter devices and in some cases ceramic filters devices are the usual point-of-use household water filtration options people use for safe water consumption. Although point of use water treatment devices have a significant contribution in removing microbial contaminants, physical and chemical pollutants and improve water quality and safety, there is limitation in knowing their efficiency in removing such contaminants at longer time usage. Despite point of use filtration devices have limitations, their popularity as interventions in removing waterborne microbes and undesirable pollutants from water are increasing in many countries where absence of treatment facilities and inefficient disinfection risks people's health (Jerome et al., 2018). Therefore, the main objective of this study was to assess the effectiveness of different point of use water filtration devices used at household in reducing bacteria from the influent and effluent water samples.

MATERIALS AND METHODS

Experimental design and sampling

The study employed experimental approach to evaluate the bacterial removal efficacy of point of use filter devices from water samples supplied via distribution systems at Institute of Biotechnology laboratory, Addis Ababa University. In this study, four point of use filter devices; membrane filter, membrane with activated carbon filter, ceramic candle type filter and hybrid (multistage) filters were set in the laboratory as depicted by the schematic diagram as shown in Figure 1 and evaluated for their bacterial removal effectiveness from treated water used at household. The filter devices were obtained from the local market in Addis Ababa.

Pyrex glass sampling bottles, plastic bucket (5-L each) and Petri-plates were aseptically prepared for sample analysis. Distilled water and 80% ethanol were used for disinfecting the buckets prior to putting the filter devices (ceramic candle type and membrane filter devices) and pouring the sample water into the containers. The membrane and the hybrid filtration devices had their own containers and were set independently on the lab bench.

The influent water sample was taken from faucet mounted tap located outside the laboratory at College of Natural and Computational Sciences, Addis Ababa University. A vacuum pump filtration apparatus (Rotary Vane Vacuum Pump, Tanker 150-220V/50H,187130-22, Taiwan) was set in the laboratory for sample filtration. Petri-dishes, sampling bottles, filtration apparatus (filter funnel, clamps) and flasks were pre-sterilized before sample processing. Absorbent pads, cellulose acetate membrane filter (pore size of 0.45 µm) and growth media were prepared for culturing bacteria following standard methods for water quality analysis (APHA, 2017).

Sample filtration and analysis

Membrane Lauryl Sulphate Broth (MLSB) was used for culturing of total coliforms (TC) and fecal coliforms (FC). Slantez and Bartley agar media and R2A agar were prepared for fecal *Streptococcus* (FS) and for heterotrophic bacteria plate counting (HPC), respectively. About 100 mL water sample as influent from faucet mounted tap and filtered using 0.45 µm filter paper for TC, FC, and FS analysis. For HPC analysis, 100 ml of diluted sample (1 mL sample water diluted with 99 mL buffered with distilled water) was filtered on to a 0.45 µm pore size sterile membrane filter and the filter paper was placed on to a 50 × 9 mm Petri-dish where 15 mL of the liquified R2A agar was dispensed on to it. The incubation temperature for plates containing total and fecal coliforms respectively was 37°C for 24 hours and 45°C for about 24 h. All yellow colonies were counted using digital colony counter and recorded as CFU/100 mL. Plates containing faecal *Streptococcus* were incubated at 44°C for 48 h and reddish-purple coloured was counted whereas HPC plates were incubated at 28°C for 5 days and all cream-colored colonies were counted and recorded in CFU/mL.

To analyze TC, FC, FS and HPC from effluent water from each point of use filter devices set in the lab, 5-L plastic bucket was prepared and disinfected with 80% ethanol after washing with distilled water. The filtration apparatus was set with the same procedure as influent sample analysis. About 5 L of water from faucet mounted tap was poured at each point of use filter devices set in the laboratory for filtration. Then, from each of the four point of use filter devices, separate sampling bottles were prepared and used for taking 300 mL filtrated water sample for further culturing of indicator organisms. For each sample again, a separate filter paper was aseptically prepared and 100 mL sample water put on to filter funnel and then filtrated using vacuum pump pressure. Filtration process, culturing, and incubation of organisms employed the same procedure as influent sample analysis.

Data analysis

All the data were analyzed using IBM SPSS v.23. The bacterial removal efficiency of the filter devices were computed based on percent reduction efficiency using the following equation.

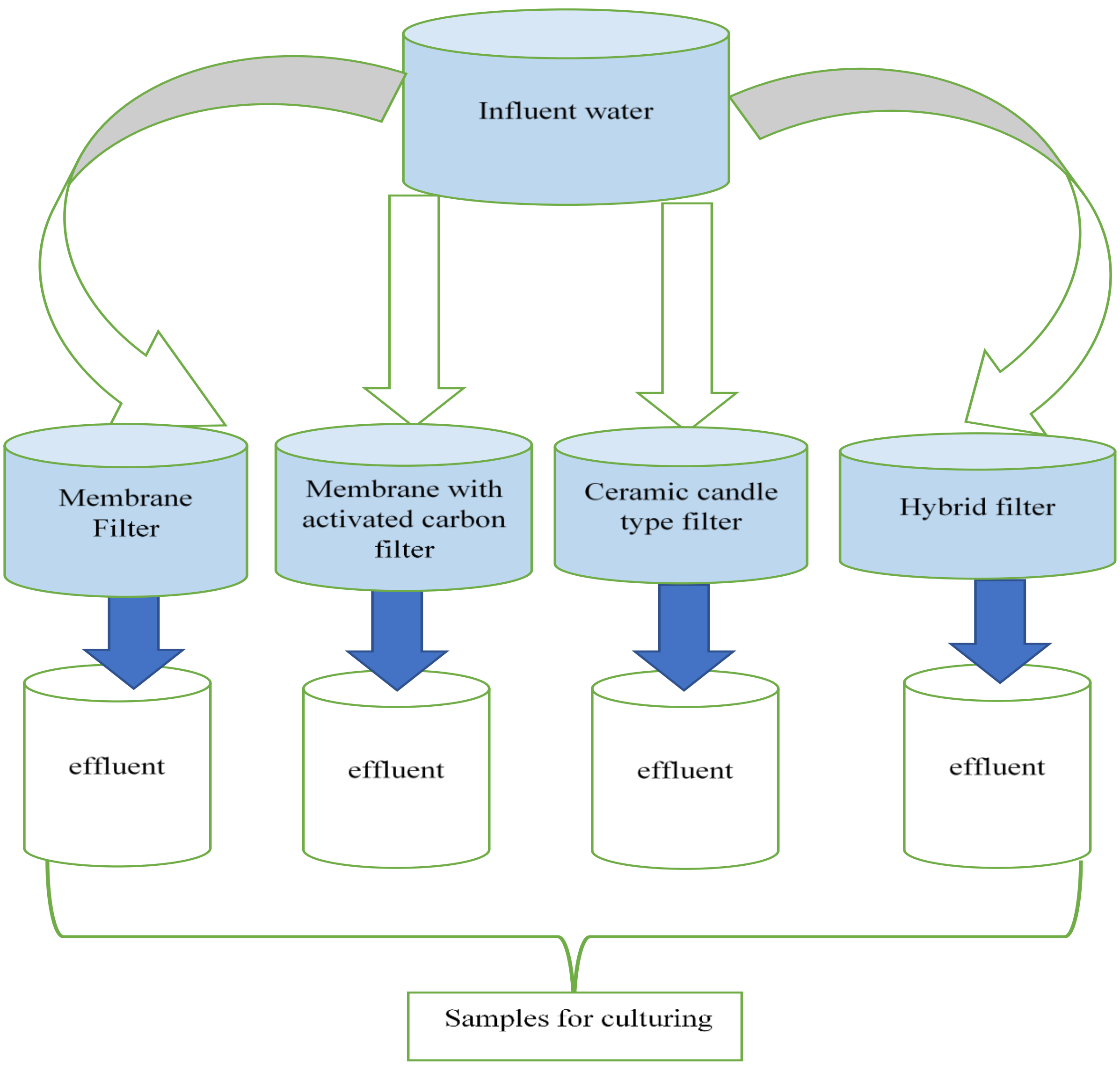

Figure 1. Schematic diagram representing set up of point of use filter devices in the laboratory.

%Reduction = (Influent - Effluent / Influent) × 100

A two tailed test at 5% significance (P<0. 05) was used for establishing the difference between the removal efficiency of filter devices during the three consecutive days.

RESULTS AND DISCUSSION

The microbial removal efficiency of four filter devices used at household level was evaluated using water quality indicator organisms, total coliform (TC), fecal coliform (FC), heterotrophic bacteria (HPC) and fecal *Streptococcus* (FS) (Figures 2 to 5). The results revealed that membrane and membrane with activated carbon filter devices showed good total coliform removal efficiency of 51.4 and 58.2% on the first day. These devices, respectively, achieved better removal efficiency of 78 and 74.5% on the second day. On the other hand, hybrid filter device had lower total coliform removal efficiency (42 and 25.5%) on the first and second days of filtration compared to the other filter devices. The flow rates measured for each filter devices had a decreasing trend after the first day filtration shown in Table 1 which indicated that efficiency of filtration of each filter device over consecutive days of usage decreased, may be due to clogging of organic matter and debris on the surface of the filters and hence be conducive platform for bacteria growth and multiplication.

Hence, membrane and membrane with activated carbon filter devices were better in removing microbial contaminants compared to the other filter devices on the first and second days. Similarly, Mark et al. (2016) also

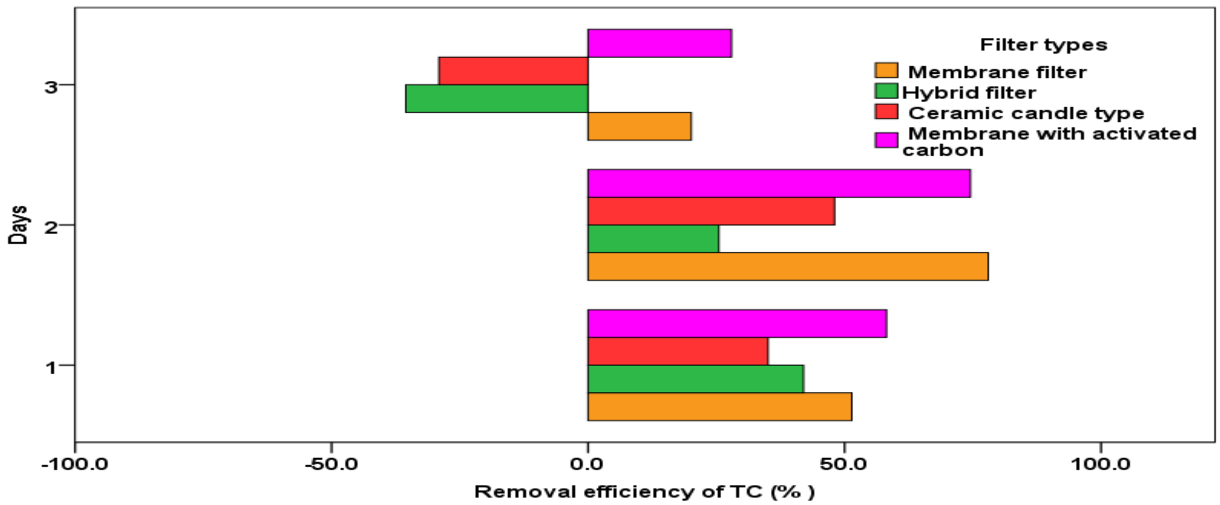

Figure 2. Removal efficiency of total coliform among the four point of use filters over the three days.

Table 1. Flow rates of the filter types measured at each filtration day.

Filter type	Flow rate/minute		
	Day 1	Day 2	Day 3
Membrane filter (ml)	120	110	100
Membrane with activated carbon (ml)	117	105	100
Ceramic candle type (ml)	110	95	90
Hybrid filter (ml)	125	115	100

showed drastic reduction in total and fecal coliforms from 65% in influent water samples to 3% in post filtered water samples by using membrane filter devices.

As observed from Figure 2, on the 2nd day of testing, there were better total coliform removal efficiency of membrane filter (78%), ceramic candle type (48%) and membrane with activated carbon (74.5%), except the hybrid filter devices which had removal efficiency of 25.5%. But on the 3rd day, there were significant number of total coliform bacterial counts measured from the filtered water indicating all filter devices were not that efficient in removing bacteria where membrane filter decreased from 78 to 20%, membrane with activated carbon filter decreased from 74.5 to 27% but hybrid and ceramic candle type, respectively had negative removal efficiency (-35.5 and -29%) of post filtered sample where the number of bacteria count of each respective filter were 167 and 160 CFU/100 mL compared to influent sample each having 123 CFU/100 mL bacterial count. This, on the other hand, indicates the failures of such filter devices in effectively removing biological contaminants as the lifetime of the filter devices longer. Despite the fact that the filter devices were expected to improve water quality by reducing bacterial load from the effluent water, this intervention did not achieve a satisfactory improvement in drinking water quality at point of use, probably, because of poor filter handling practices and its use in an environment with low hygiene and high loads of fecal bacteria in the households.

Even though parasite and viral removal efficiency of filter devices were not tested, the removal efficiency of ceramic and membrane point of use filters in this study was much lower than 99.9% efficiency of removing different bacteria, viruses, and parasites (Kathleen et al., 2017). However, this finding is consistent with a research which indicated that filtered water had higher bacterial count than the influent water on the third life time of point of use filter devices (Su et al., 2009). The results also conform with a research which indicated low bacterial removal efficiency where filtered water had higher bacterial count than influent water on the third life time of membrane and ceramic point of use filter devices. This was due to organic matter retained inside the filter devices which supported the growth of different bacteria and hence lead to the development of biofilms which in turn causes filtered bacteria to increase (Clark and Elmore, 2011).

The other suggestion might be point of use filter devices may create favorable conditions inside where coliform organisms may regrow and hence detected in

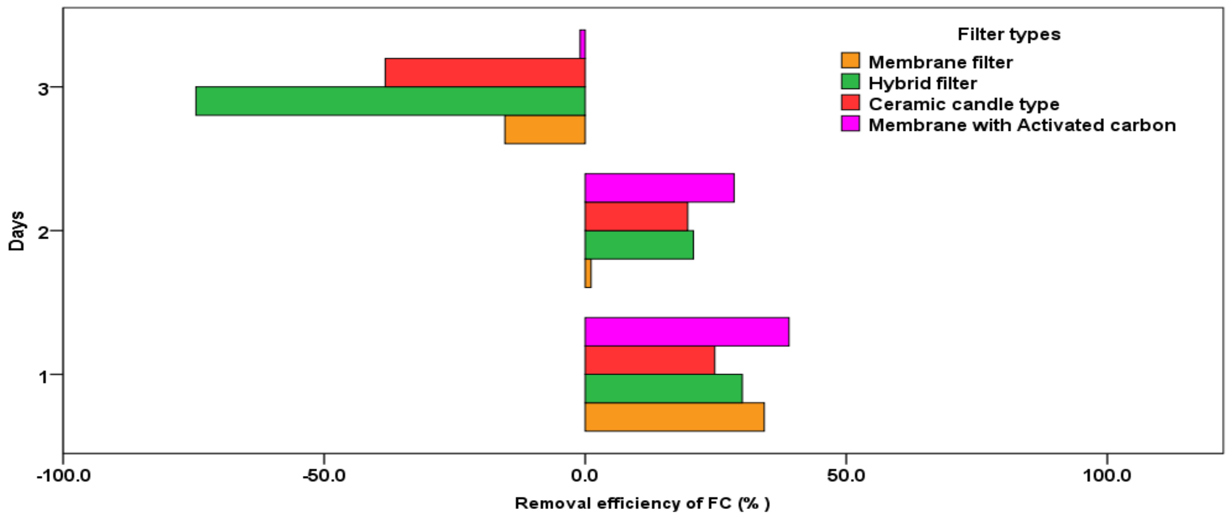

Figure 3. The removal efficiency of fecal coliform among the four filters over three days.

significant number in water coming out from the filter devices (Filipe et al., 2018). Moreover, particulate matter collected inside filter devices reduces flow rate of the filter devices which then contributes strong adhesion intensity of bacteria inside the filter devices and hence this would help to form biofilm and a high number of bacteria measurements in the effluent water (Su et al., 2009). Despite the use of the filter devices, the filtration did not achieve a satisfactory improvement in drinking water quality at the point of use, probably, because of poor filter handling practices and use in an environment with low hygiene and high loads of fecal bacteria in the households when people manage using contaminated hand.

The fecal coliform removal efficiency of the four filter devices is as shown in Figure 3 and in the first day of filtration, membrane filter, hybrid, ceramic candle type and membrane with activated carbon had removal efficiency of 34, 30, 24 and 39%, respectively which is then lowered to 1.1, 20.7, 19.6, and 28.5%, respectively on the second day. On the 3rd day, the removal efficiency of the filter devices was negative which means the number of bacteria counted from the effluent water were significantly greater than the influent water samples ($P>0.05$).

Similarly, the removal inefficiency of ceramic and membrane filter devices of fecal coliform and *Escherichia coli* over time was due to concentration of bacteria inside the pore spaces and when filtration process proceeds in the next day, bacteria can simply move out into the effluent water (Clark and Elmore, 2011).

Another study also showed that the decrease in bacterial removal efficiency of these point of use filter devices used at household may also be due to the lack of performance enhancing chemicals that could remove organic matter inside pore spaces and also the absence of elements like silver impregnation on the filter devices (Jocelyne et al., 2013).

The HPC removal efficiency of the devices is as shown in Figure 4 and on the first and second day of filtration, except membrane with activated carbon filter device; hybrid, membrane and ceramic with candle type filter devices had better removal efficiency (37, 32 and 26% on the first day whereas 42, 36, and 24% on the second day) but on the third day of filtration, hybrid and membrane filter had each 50% HPC removal efficiency and the other two, membrane with activated carbon and ceramic candle type filter showed 25 and 29% of HPC removal efficiency, respectively.

The reduced HPC removal efficiency of ceramic candle type filter on the first and second days of filtration (-12 and -4%, respectively) in this study may be associated with accumulated organic impurities inside filter pores which helped HPC bacteria to attach themselves and form gradually biofilms so that the bacteria remain there unlike the total coliforms, fecal coliforms and fecal *Streptococcus* (Syreeta et al., 2009).

Regarding the removal efficiency of fecal *Streptococcus* (Figure 5), all filter devices showed declining efficiency on the 2nd and 3rd days (membrane, hybrid, ceramic candle and membrane with activated carbon filter devices declined by 32, 87, 60 and 15% removal efficiency on the second day and 30, 14, 26 and 6% on the 3rd day, respectively) unlike on the first day of filtration (which had removal efficiency of 33, 27 and 17% except hybrid filter device). This was supported by a study done on a batch tested research on the efficacy of ceramic siphon household water purification device that showed the decrease in the removal of pathogenic organisms including *E. coli* decrease over time (Amanda et al., 2011).

The declining problem in performance of ceramic and

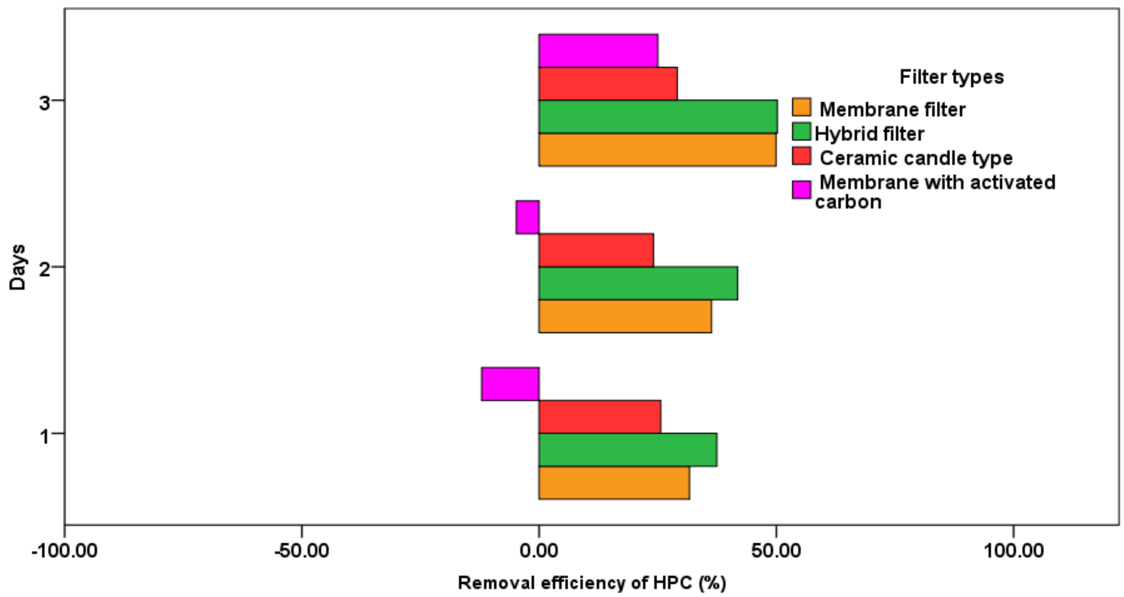

Figure 4. Removal efficiency of heterotrophic bacteria (HPC) among the four filters over three days.

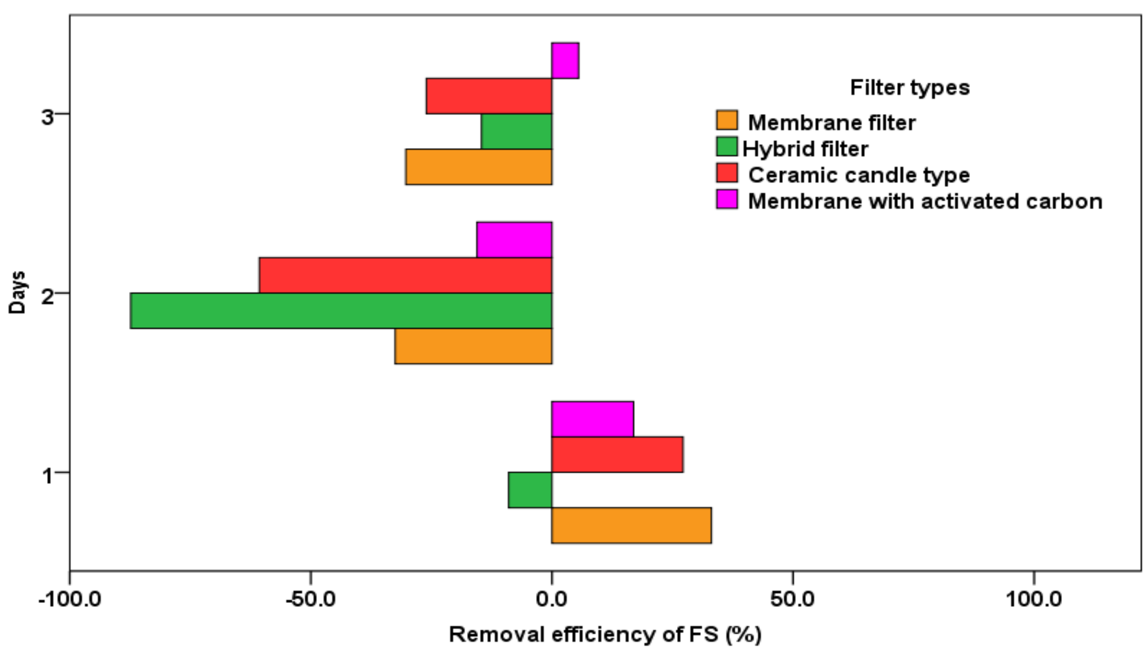

Figure 5. Removal efficiency of fecal *Streptococcus* among the four filters over three days.

membrane filter devices in bacterial removal when the life span is extended can be solved with maintaining regular cleaning practices which further improves flow rate although such practice is reported to decrease the life span of ceramic and membrane filters devise used at household (Jacqueline et al., 2010). Other possibility which is indicated to enhance bacterial removal performance of household point of water purification filter devices is the incorporation of hydroxyapatite into ceramic water filters which increases the percentage of porosity which intern has greater efficiency in removing bacteria than conventional filters (Mark et al., 2008).

The bacterial removal performance of the filter devices used in this study was irregular at each testing day. Such ineffective performance of the filter devices over the three consecutive days may be due to the presence of organic matter and other contaminants in which intern leads to change in the quality of water tasted on the three days (Md Rezaul et al., 2016).

Conclusions

The use of filter devices to further treat water at point of use showed that on the first day of testing, membrane and membrane with activated carbon filter devices only were more efficient in removing total and fecal coliforms. However, they showed a decrease in their efficiency in removing bacteria from tested water as the life span of usage is longer. The number of HPC, FS and the coliforms were high in the effluent water on the second and third day of testing. Therefore, point of use filter devices used for household water treatment in reducing microbial and other physicochemical contaminants should be cleaned regularly and replacing non efficient devices after longer time usage with new one so that health risks caused by such contaminants can be avoided.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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