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PERFORMANCE OF WATER FILTERS TOWARDS THE REMOVAL OF SELECTED POLLUTANTS IN ARUSHA, TANZANIA

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ABSTRACT

This paper presents the findings of a study carried out to investigate the efficiency of selected common water filters in the removal of Escherichia coli, organic matter and fluoride. Additionally, the Total Suspended Solids, Turbidity and colour were also considered for assessing the performance of the filters in ensuring safe water provision. The results showed that various filters performed differently at particular retention times. Removal of Escherichia coli, was found to be 100%, 75%, 96%, 96.5, 98.5%forbio-sand, slow sand, ceramic, bone char and membrane purifier respectively. Organic matter removal was found to be 47%, 43%, 53%, 43.4% for bio-sand, slow sand, ceramic and membrane purifier respectively, while, fluoride removal was found to be 95.5% for bone char filter. Furthermore, filters were also assessed in terms of media availability, buying costs, operation, benefits/ effectiveness towards major pollutants, and drawbacks.

The study concluded that filters currently present in the market especially in Arusha are effective towards specific pollutants. To remove multiple pollutants, an integrated filter would be needed for optimized performance.

Key words: water filters, water purification, *E. coli*, organic matter, fluoride

INTRODUCTION

Inadequate access to safe water is the main contributor to waterborne and water associated diseases in developing countries (Prüss et al. 2002, Brown 2007, Montgomery and Elimelech 2007, Albert et al. 2010). Particularly, susceptible are children under the age of five, who are the most vulnerable to diarrhoea and other waterborne diseases (Malapane et al. 2012, Modellet al. 2012). Provision of water using central distribution system is a good option, however, in developing countries distribution systems are often plagued by high capital costs, lack of proper operation and maintenance, and an over-reliance on treatment technologies that cannot be afforded or maintained (Montgomery and Elimelech 2007). Moreover, it is illogical to think that a poor country can develop the water distribution network covering the rural areas where infrastructure to support such investment is minimal. Most of communities lacking access to safe water are therefore those in remote location, which leads to the need of not only having improved access but also a better means to provide potable water (Kennedy et al. 2013). In response to this problem several technologies are used globally to treat water at the point of use namely; chlorination, coagulation/chlorination, solar disinfection, boiling, and filtration (Mintz et al. 2001, Montgomery and Elimelech 2007, Lantagne et al. 2008, Barstow 2010, Fiebelkorn et al. 2012).

The main drinking water risks in developing countries are associated with microbial pollution. Access to safe and clean water is the core element to basic needs and human rights. Only 80% of urban and 47.9% of rural dwellers in Tanzania have access to improved water sources according to Tanzania Demographic and Health Survey (TDHS 2010).

It is further reported that only 22% of urban and 9% of rural have access to improved sanitation. This demonstrates the gap that exists between urban and rural towards safe water, sanitation and hygiene (TDHS 2010)**.**

Lack of access to safe and clean water in Tanzania is a result of contamination of surface and groundwater. This contamination is primarily by pathogenic bacteria, mainly, through improper disposal of human excreta coupled with wastewater containing organisms of enteric diseases. This occurs at water sources or during conveyance of water from the source to consumer. In some regions such as Arusha, surface and groundwater is also contaminated by natural mineral elements such as fluoride, which exceeds the world health organization guidelines of 1.5mgF/L (WHO 2003).

Various point of use treatment technologies have been adopted in Tanzania as the response to unsafe drinking water. These include disinfection, boiling and, filtration. Filtration technologies seem to be viable compared to boiling and disinfecting because it is less expensive in terms of affordability and it is easy to use and maintain.

Depending on the local criteria of water quality in Tanzania specifically in Arusha region the most common water filters used are (i) Ceramic water filter, (ii) Bone char filter, (iii) Bio-sand-filter, (iv) Slow sand filter, and (v) Membrane purifier.

Health benefits for filtration technologies in terms of diarrhoea reduction have been fairly well documented worldwide (Duke et al. 2006, Stauber et al. 2006, Oyanedel-Craver and Smith 2007, Stauber et al. 2011). However, some filter studies report some filtration technologies to produce water with residue pollutants that are above recommended limits for drinking water (Brown 2007, Lemons 2009). Other studies reported further that, water filters are efficient towards removal of one-pollutant not all-potential pollutants present in water (Sobseyet al. 2008, Kuchewar and Nagarnaik 2012). Moreover, water filters differ in design and operation properties due to technology and materials used that vary from one place to another resulting into variation in their performance for specific water pollutants. In Tanzania water filters are normally used to deal with all potential pollutants in water. Therefore, the present study aims at examining the performance of selected water filters available in the Tanzanian market to remove physical, chemical and biological contamination from selected source of water and thus, providing information about the quality, performance and contaminant removal capabilities of the water filter products.

MATERIALS AND METHODS

Materials

A market survey was carried out in Arusha town in order to identify the most commonly used filters prior to the purchase of water filters for various experiments. Five types of filters, which are (i) Slow sand filter, (ii) Bio-sand filter, (iii) Ceramic filter (iv) Bone char and, (v) Membrane purifier (Plate 1) were found to be commonly used, and thus, purchased from the market. Other less commonly used filters found in the market include candle filter, siphon filters, and filter poa. For comparison purposes, slow sand filter made at Nelson Mandela African

Institute of Science and Technology in collaboration with Purdue University was also included in the study. The choice of commercially available filters was in accordance to the quality of water sources in Arusha region. The five types of filters collected for the study used different types of processes to remove impurities such as chemical, biological and physical mechanisms.

Plate 1: Water filters used for study

Methods

Water samples were collected during the dry season and these samples were collected from a surveyed river. Selection of representative river and parameters to be tested solely depended on the use purposes of the river water and the extent through which the targeted communities are vulnerable to waterborne diseases. Survey revealed that, Themi River particularly downstream, present an ideal sampling site due to the fact that some anthropogenic runoff and other solid wastes from the Arusha city were found at this point. Moreover, it was far observed that, residents are using this point as the drinking site for their cows. Furthermore, during the survey the interview was done to the group of women who were found collecting water from this site, and it was observed and concluded that this water, which is untreated, was used also for domestic purposes for both near and far residents.

Collection of water samples

Water samples were collected from Themi river (Lokii) with UTM locations of Easting’s 252441, Northings of 9612195 and elevation of 1092m. Raw water was collected using twenty (20) litre containers and taken to Nelson Mandela laboratory for analysis. In situ determination of some physical-chemical parameters including pH, Electronic Conductivity, temperature, total dissolve solids was done using Multi-parameter HI 9829.Furthermore, turbidity and colour were determined using turbidity meter HI 93703 and spectrophotometer HAC DR 2800.Water chemical analysis of the remaining parameters was done at Nelson Mandela using standard analytical procedures (APHA 2005), where Total suspended solids were determined by gravimetric method, BOD_5usingOxiTop®,Fluoride using fluoride meter, and of *E. coli* usingMethod 1604:(Oshiro 2002), Total Coliforms and *E. coli* in Water by Membrane Filtration Using a Simultaneous Detection Technique (MI Medium), respectively.

Batch experiment

Forty liters (40) of water samples were introduced to the filtration systems in a batch to establish the efficiency of water filters. Varying retention time was applied to treat water sample with known characteristics. Retention time of five (5) days, four (4) days, three (3) days, two (2) days and, one (1) day were used. Treatment efficiency was determined in accordance with the equation (i).

$$E = \frac{C_o - C_f}{C_o} X100 \quad \text{……………..….. (i)}$$

Where: C_o is initial concentration of a mentioned parameter in the water sample at t_o, $C_f$is the final concentration of the mentioned parameter and **E** is the efficiency of the water filter.

Statistical Analysis

Descriptive statistics were used to characterize the water quality testing results from natural water samples where sigma plot 11, was used. This analysis includes normality test at 95% confidence interval, mean and, standard deviation. Comparisons were made using paired sample t-test and all tests were compared using a significant level of $p \leq 0.05$. Graphs were drawn using origin pro lab version 8.6 which helped in attaining the trend of performance of selected water filters.

RESULTS

Water quality of the raw water

Table 1: Water quality analysis for physical, chemical and biological parameters of the raw water used for study.

Parameters	Average Values
pH	8.56
Conductivity (µS/cm)	710
Temperature (°C)	21.35
Total dissolved solids (mg/l)	354
Dissolved oxygen (mg/l)	3.2
Total suspended solids (mg/l)	10
Colour (Ptco)	34
Turbidity (NTU)	1.34
Fluoride (mg/l)	3.47
Biochemical oxygen demand (mg/l)	6
Escherichia coli (CFU)	9167

Efficiency of water filters for *E. Coli* removal

Results from laboratory reduction of *E. coli* are illustrated in Figure 1. In the first run(1 day retention time) of filter dosing experiments removal efficiency was greatest for bio-sand filter that is (100%) whereas, ceramic, slow sand, bone char and, membrane filters had removal efficiencies of 94%, 54%, 92% and, 98%, respectively.

In the fifth run(five days retention time) the four filters (ceramic, slow sand, bone and, membrane purifier) were able to attain maximum *E. coli* efficiency removal of 100%, which suggested the potential importance of retention time in filter bed to enhance microbial removal. Paired sample t-test at 95% confidence interval revealed that the comparison mean of selected filters towards *E. coli* removal was statistically significant with p values less than 0.05($p \leq 0.05$). The improvement in *E. coli* reduction during the length of batch experiment to filters was shown below.

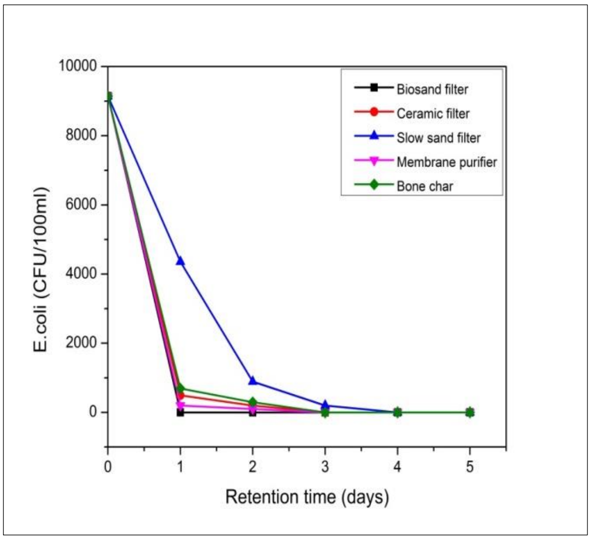

Figure 1: *E. coli* concentration with time for various filters in natural water experiments

Efficiency of water filters towards fluoride removal.

Figure 2 shows the results on fluoride reduction from natural water experiment. On an average the bone char reduced the original content of 3.47mgF/L in raw water to 0.352mgF/L in treated water that is 89% removal efficiency in one-day retention time. When the raw water was allowed to come into contact with treatment media for five days the concentration of fluoride in treated water dropped to 0.023-mgF/L implying 99.33% removal efficiency. Both for the first run (1 day retention time) and the fifth run (5days retention time) filtration the treated water met the WHO recommended limit of 1.5mgF/L. Statistical t-test at 95% confidence interval revealed that the comparison mean on fluoride removal that occurred with the treatment was statistically significant with p values of 0.01 which is less than 0.05. The remaining four filters namely; bio-sand, ceramic, slow sand, and membrane purifier showed no significant reduction of F^- concentration where p values were 0.146, 0.287, 0.214 and 0.246, respectively. The values are greater than 0.05 ($p \geq 0.05$) showing that the materials used for filters building up had no ability of reducing fluoride content in raw water.

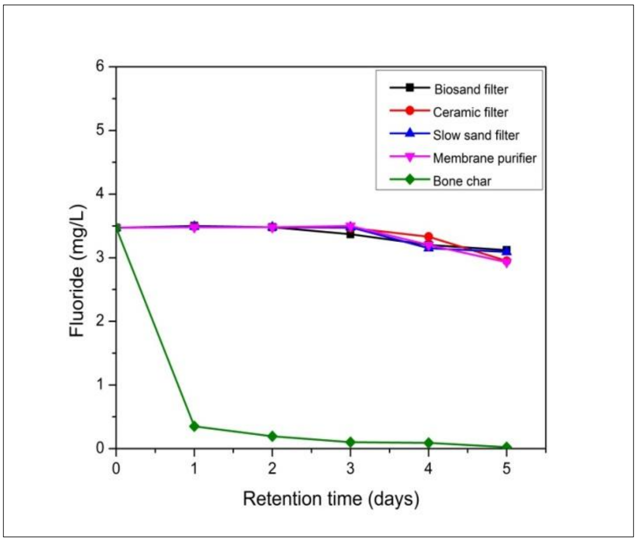

Figure 2: A plot showing fluoride removal by various filters in natural water experiments

Efficiency of water filters towards organic matter removal.

Figure 3 presents the results on organic matter removal. The four filters namely bio-sand, ceramic, slow sand and, membrane purifier showed ability to reduce levels of BOD_5 from 20% to 70% depending on the contact time between the media and the water sample.

Statistical t-test at 95% confidence interval revealed that BOD_5 removal by various filters was statistically significant with p values of 0.002, 0.001, 0.004 and 0.002 for bio-sand, ceramic, slow sand filters and membrane purifier, respectively. The values are less than 0.05 ($p \leq 0.05$). 20%removal efficiency at the first run (1 day retention time) of filter dosing experiments can be explained as functions of micro-organisms which had to become acclimatized to new environment but also the condition such as dissolved oxygen and temperature which are important in the whole process.

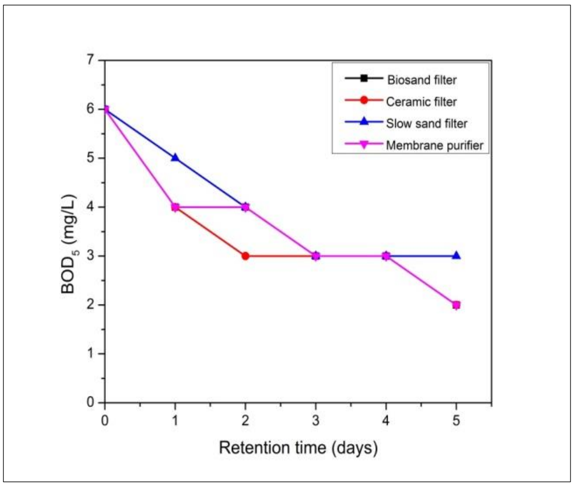

Figure 3: A plot showing variation in BOD_5 removal with time by various filters in natural water experiments

Efficiency of water filters towards Turbidity removal

Figure 4presents the results on turbidity removal. All filtrates from first run (I day retention time) were within the WHO recommended limit of 6mg/L. Bio-sand, ceramic, slow sand, bone char and, membrane filters showed the removal efficiency of turbidity of up to 100%.

Statistical t-test at 95% confidence interval revealed that the comparison mean on turbidity removal by water filters was statistically significant with p values of 0.00, which is less, or equal than 0.05 ($p \leq 0.05$).

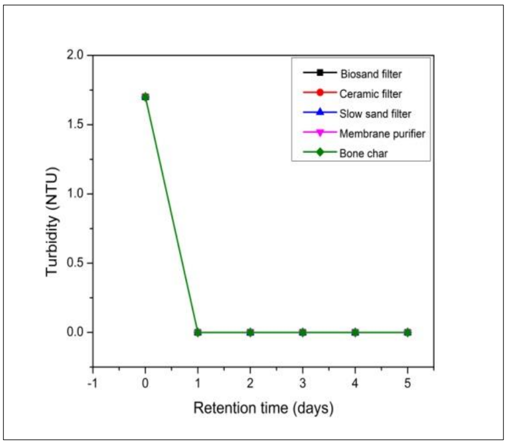

Figure 4: Variation in levels of Turbidity removal with time from field water experiments by various filters

Efficiency of water filters towards Total suspended solids removal

Figure 5 shows the removal ability of the test water filters towards total suspended solids (TSS), which varied from 70% to 100%. Statistical t-test at 95% confidence interval determined that the comparison mean on TSS removal by selected filters was statistically significant with p value of value of 0.00, which is less than 0.05 ($p \leq 0.05$).

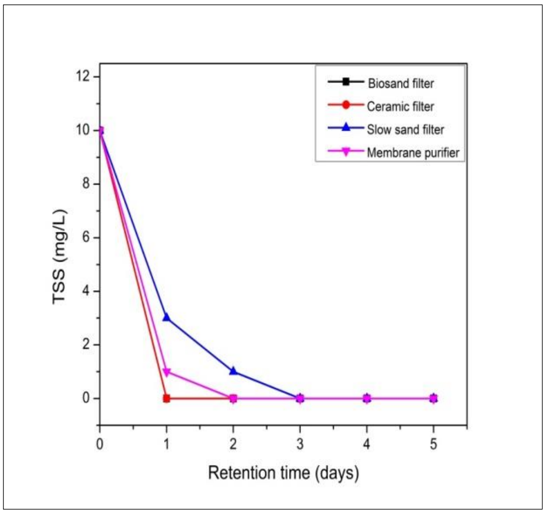

Figure 5: TSS removal at different retention times by various filters in field water experiments

Efficiency of water filters towards colour removal

Results from Figure 6 showed colour reduction from source water by five selected filters, which varied from 20% up to 100%. During the first run (1 day retention time) removal efficiency was greater to membrane filter that is 79%. Whereas bio-sand, ceramic, slow sand and, bone char had removal efficiencies of 64%, 32%, 31%, 5%, correspondingly. In the fifth run(five days retention time) the four filters (bio-sand, ceramic, slow sand, and bone char) were within the levels recommended by WHO of less than15 PtCo. Paired sample t-test at 95% confidence interval determined that the comparison mean on colour removal by selected filters was statistically significant with p values of 0, 0.004, 0.004, 0 and 0.025 for bio-sand, ceramic, slow sand, membrane purifier, and bone char, respectively

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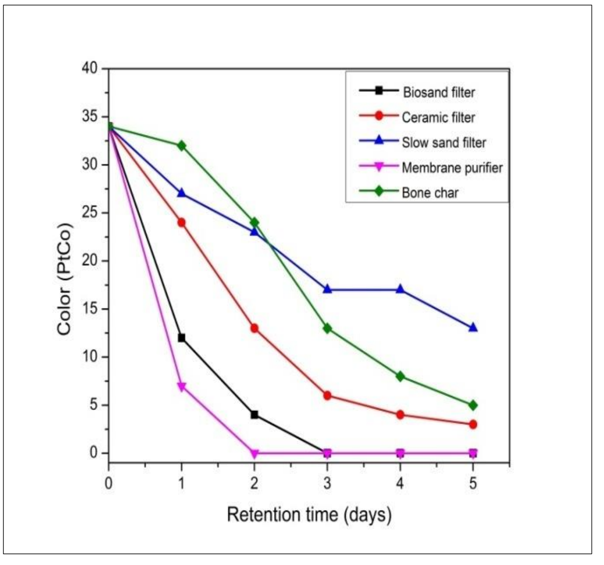

Figure 6: A plot showing variation in Colour removal with time from field water experiments by various filters

Table 2: Evaluation of water filters

Types of filters	**Media**	**Local Availability of the media**	**Buying costs**	**Benefits and major pollutants treated**	**Easy to Use**	**Drawbacks**
i. Bio-sand filter	Sand and gravels	High	$ 71	i. High flow rate, and visual improvement of water. ii. Produced using locally available materials. iii. It is installed- once with low maintenance requirements. iv. Highly effective towards bacteria removal, through development of biological layer, which acts as predator towards pathogens, but also turbidity and, Organic matter removal.	Easy	i. Difficult in transportation due to its heavy weight. ii. Sudden change in flow rate may disturb the biological layer thus, reducing its effectiveness.
ii. Ceramic water filter	Clay and, other minerals	i. Varies from place to place. ii. Variation in fabrication skills.	$ 71	i. Effective towards bacteria removal. ii. Long life span if filter remain unbroken. iii. Installed once.	Ease to moderate, must be cleaned regularly to avoid filter clogging.	i. Variation in the quality of locally produced filters. ii. Low flow rate. iii. Filter breakage. iii. Receptacle and, filter need to be regularly cleaned. iv. Filter cleaning reduces its effectiveness.
iii. Slow sand filter	Sand	High	$ 28	i). Produced using locally available materials.	Ease to moderate	i. Difficult in transportation. ii. Sudden change in flow rate

				ii) One–time installation with low maintenance required. iii) Effective towards bacteria removal, through development of biological layer, which acts as predator towards pathogens.	(suitable for community use).	may reduce its effectiveness due to destruction of biological layer.
iv. Bone char	Charred cow bones	High	$ 19	i). Produced using locally available material. ii) Effective towards fluoride and arsenic removal in drinking water.	Ease	i. If media are not well prepared they may produce odour and taste. ii. The media need to be changed as soon as the quality of produced water does not meet the acceptable levels for drinking.
v. Membrane purifier	Membrane, activated carbon, and other extra filter bags for lime, arsenic and heavy metal.	Low	$ 81	i. Effective towards bacteria removal. ii. Effective in colour and, odour reduction.	Difficult to use since the user has to have the knowledge on proper packing of the media for effective use.	i. Expensive due to the fact that media are locally unavailable. ii. The water to be treated needs pretreatment to avoid membrane clogging. iii. Excessive cleaning can cause membrane damage.

DISCUSSION

All filters had undergone previous laboratory testing (as shown in Figure 1 to Figure 6) towards physical, chemical and biological parameters prior to current evaluation.

Point of use filtration technologies are designed for home use and thus, issues related to cost, operation, easiness on maintenance, local availability of the media, and the ability of achieving high removal rates of pathogens are of greatest importance. Evidence from this evaluation and laboratory experiments has shown that both bio-sand and bone char filters are robust and capable of providing safe water to users provided that the structural element remains sound. Bio-sand showed higher removal rates of pathogens figure 1, with the p value of 0.01. Excellent performance of BSF towards bacteria is also reported, (Kaiser 2002, Stauber 2006) to consistently reduce bacteria up to 99%. On the other hand bone char showed greatest performance on fluoride removal figure 2, with the p value of 0.01. Unlike bone char whose efficiency dropped with time, bio-sand filter continued to perform well within the expected range of filter testing. The exhaustion of bone char when used continuously is also reported (Mjengera 1988) which needs replacement or regeneration. The remaining three filters (ceramic, slow sand and, membrane filter) showed an average performance towards reduction of potential parameters (as shown in figure 1 up to figure 3) namely; *E.coli*, organic matter and, fluoride.

CONCLUSION

This study has revealed that producing safe water at household level using point of use (PoU) technologies require understanding of the typical pollutants being targeted. There is no "fit for all" PoU technology for the treatment of water at the household. Laboratory results where five household filters were dosed with natural water samples showed different levels of reduction of the various pollutants present in the water namely *E.coli*, organic matter, fluoride, turbidity, total suspended solids and, colour (as shown in figure 1 up to figure 6).While bone char filter is excellent for Fluoride removal figure 2, bio-sand, ceramic, slow sand, and membrane filters are good for the removal of *E.coli* Figure 1. The four filters namely ceramic, slow sand, bone char and membrane filters have shown to perform well in the removal of TSS and Turbidity. Removal of colour varied between these filters where membrane filter showed the best results figure 6 while, bone char and sand filter showed the poor performance figure 6. Design of PoU system for providing safe water from water sources in Arusha, which are known to contain multiple pollutants would need an integrated filter composed of three main parts (i) TSS/Turbidity and organic matter removal (ii) fluoride removal and, (iii) complete disinfection.

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