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Effectiveness of household-installed bio-sand water filters in Morogoro, Tanzania

Jamal Bakari Kussaga* and Neema Moirana

Department of Food Science and Agro-processing, School of Engineering and Technology, P. O. Box 3006, Morogoro, Tanzania.

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This study assessed the handling and effectiveness of Bio-Sand-Filters (BSFs) in filtering water for human drinking purposes in households within Morogoro Municipality, Tanzania. Water microbiological parameters (such as Escherichia coli, total viable counts (TVC), and total coliforms) and physico-chemical properties (including turbidity and pH) were analyzed before and after filtration. Escherichia coli levels were below the quantification limit (<1 Log CFU/ml) in the unfiltered water, while TVC ranged from 2.2 to 2.9 Log CFU/ml and coliforms ranged from <1 to 2 Log CFU/100 ml. In filtered water samples, both total viable counts and total coliforms significantly decreased to <1 Log CFU/ml. Turbidity reduced from 7 Nephelometric Turbidity Units (NTU) in unfiltered water to 6 NTU in filtered water samples. The pH of unfiltered water samples varied from 6.5 to 7.7, whereas that of filtered water ranged from 6.8 to 7.8. Overall, BSFs can significantly reduce microbiological contamination and water turbidity to meet required standards without the need for thermal or chemical treatments. This water filtration technique is relatively cheaper than conventional boiling and chemical treatment methods, making it the best option for resource-poor households.

Key words: Bio-sand filter, water microbiology, water filtration, turbidity, pH, Nephelometric Turbidity Units (NTU), total viable counts (TVC).

INTRODUCTION

The quality of water is among the important aspects to be considered in ensuring public health. Water treatment and/or filtration are highly regulated in all governments across the world. However, not all countries, particularly emerging and developing ones, have adequate safe public water supply. In developing countries, urban areas have a relatively large number of households accessing public water supply compared to rural areas. For instance, in Tanzania, 86% of people living in urban areas have access to safe water supply, whereas in rural areas, only 74.5% do (United Republic of Tanzania, 2022).

Various technologies (such as coagulation, filtration, boiling, disinfection) to treat water at the point of use (POU) have been developed (Kiagho et al., 2016). Among the oldest methods of water filtration is Slow Sand Filtration (SSF), which has been used since the 1800s (Sobsey et al., 2008). In the late 1980s, the traditional SSF was improved to a smaller-scale filter known as a Bio-Sand Filter (BSF). In bio-sand filters,

*Corresponding author. E-mail: kussaga@sua.ac.tz.

water percolates slowly through a layer of filter medium (sand), and microorganisms form a bacteriological purification zone atop and within the sand, effectively removing harmful pathogens from microbiologically contaminated water (Lea, 2008).

Compared to other water filtration methods, BSF are relatively easy to maintain, operate, and does not require power (Loo et al., 2012; Peter-Varbanets et al., 2009). Onsite water treatment using POU technologies is more practical and sustainable than the delivery of treated water (Peter-Varbanets et al., 2009; Loo et al., 2012). Although a number of POU technologies may use disinfectants (such as chlorine and iodine) to ensure water quality and safety, BSF does not require any further treatments like disinfection. It is a cost-effective method used by low-resource households to reduce public exposure to chemical hazards in water (Romero et al., 2020; Sobsey et al., 2008; Stauber et al., 2006; Mutemi et al., 2020).

Despite significant improvements in access to clean water and sanitation facilities worldwide, health issues such as diarrhea, fever, and pneumonia (Xia et al., 2004), linked to contaminated water and overuse of water sources, are increasingly reported (Cassardo and Jones, 2011), especially in developing countries like Tanzania. Lack of clean and safe water contributes to high child mortality rates in low- and middle-income countries. Water contamination stems from various sources including climate change, natural disasters (floods, volcanic eruptions, earthquakes), man-made disasters (civil and political unrest), lack of infrastructure (Cassardo and Jones, 2011), as well as anthropogenic activities such as mining, agriculture, and industrial activities. Access to potable water in the developing world remains a significant challenge even in modern times, unlike in developed countries. Households unable to access piped-water service often rely on connections from neighbors, protected/unprotected shallow wells, boreholes, and vendors using carts (World Bank, 2017). These sources are often uncontrolled and unmonitored, leading to water of uncertain quality and potentially causing waterborne diseases.

As a strategy to combat waterborne diseases and address the inadequacy of treated water in Tanzania, various companies have developed different water treatment technologies. These technologies, such as BSF (implemented by the charitable organization Serving Our Neighbors, SON), have been promoted and are being used at the household level. A bio-sand filter is an intermittently operating filter that removes pathogens and suspended solids from water using biological and physical processes (CAWST, 2009; WHO, 2022). While sand and gravel provide the physical mechanism of water filtration, a biological layer formed on the topmost 1-2 cm of sand aids biological filtration as it contains microorganisms that feed on pathogens. The BSF operates under gravity and it is not replaced but rather cleaned periodically by agitation and decanting the released contaminants and excess biological growth (Stauber et al., 2006), serving as better option for water treatment especially in poor-resourced households.

Although the BSF technology has shown great effectiveness to remove bacteria from river and rain water, post-treatment practices with chlorination (Jenkins et al., 2009) or where possible boiling is also recommended. However, at household level such intervention treatments after filtration may not be common. Moreover, studies to assess the effectiveness BSF technology in Tanzania are very limited (Kiagho et al., 2016). As yet it is not well known to what extent households depending on such water treatment technology are exposed to waterborne hazards. Therefore, the purpose of this study was to assess the effectiveness of bio-sand filters installed in various households within Morogoro Municipality. The information from this study will be useful to manufacturers of BSF, users and regulatory authorities to improve and monitor performance of these filters for public health.

MATERIALS AND METHODS

Study location

The study was conducted in three wards (that is, Mafiga, Magadu and Kihonda) in Morogoro Municipality. The study population was all households that installed bio-sand filters. Analysis of water samples was conducted at the Department of Food Science and Agro-processing, School of Engineering and Technology, Sokoine University of Agriculture, Tanzania.

Sampling of households for the study

The list of households involved in this study was obtained from the charitable organization, Serving Our Neighbor -Tanzania (SON) which constructs and provides BSFs at a subsidized cost or nominal cost in Morogoro. The organization was approached and requested to identify the households that were served with the BSFs. From the list of 100 beneficiaries, 30 households were systematically identified and included in the study. After every 3 beneficiaries of BSF, a household was selected and included in the sample. After the systematic selection of the sample (30 households) to be included in this study, the households were contacted by phone to seek for their consent to be part of the study. Out of the 30 households interviewed, 10 households were randomly selected for microbiological and physico-chemical quality analysis of water.

Assessment of handling and operation of the BSFs

All households which agreed to be part of the study were visited; BSFs evaluated and face-to-face interviews with one of the family members (especially those involved with up-keeping of the BSF) were performed. The BSFs were inspected to establish the current status. The questionnaire had 20 open-and closed-ended questions. The questions covered important aspects of SON and CAWST assessment manual. The questions assessed handling practices (12 questions) and operational condition (8 questions) of the BSF at the household level. Although the questions were constructed in English, they were translated to Swahili, Tanzania's national language to facilitate the interview.

Selection of BSF for water sample collection

The filters that met 8 parameters for a functional filter as described by SON or CAWST manual were selected for microbiological and physico-chemical quality assessment. The parameters considered for a functional filter included maturity of the filter, condition of the diffuser, flow rate, water level above the sand, sand level, outlet turbidity, daily use of filter, and filter leakage. Since the objective of the study was to assess the effectiveness of well-functioning filters, all filters which were not functioning properly were excluded for physico-chemical and microbiological quality assessments of water. The selection was also based on accessibility and the easiness of collection of the water samples in terms of geographic location and transportation. Based on the above criteria and due to the budgetary constraints, 10 filters were selected for water quality analysis.

Collection of water samples

After the identification of appropriate filters, 100 ml unfiltered water from the source and filtered water samples were aseptically collected from the BSF. Water samples were collected in sterile sample bottles; the bottles were tightly closed, kept and transported to the laboratory in a cool box with icepacks to maintain the temperature between 4 and 7°C. The samples were analysed immediately when they reached the laboratory.

Analysis of microbiological quality of unfiltered and filtered water

In the laboratory, for each water sample, 1 ml was aseptically taken into 9 ml peptone water to make 10^{-1} serial dilution; then 1 ml from 10^{-1} dilution was taken into another 9 ml peptone water test tube to make 10^{-2} serial dilutions, the procedure was repeated until the required dilutions were made (ISO, 2003). Enumerations of *E. coli,* TVC and total coliforms were performed according to ISO 4833:2003 (ISO, 2005), ISO 4833-1:2003 (ISO 4833-1, 2003), ISO 4831:2006 (ISO 4831, 2006). From each serial dilution 1 ml was taken and plated on Violet Red Bile Agar for *E. coli,* Plate count Agar for TVC and the MPN for total coliforms. The incubation conditions were 44 ± 1°C for 24 ± 2 h for *E. coli,* 30 ± 1°C for 24 ± 2 h for TVCs, and 37 ± 1°C for 48 ± 2 h for total coliforms.

Analysis of physico-chemical quality of unfiltered and filtered water

The physico-chemical analysis of unfiltered and filtered water samples involved pH and turbidity assessments.

pH analysis

The pH of the water samples was analysed by an Inolab pH 7110 Bench-top pH meter at 25°C; where the pH meter was first calibrated to set a neutral value by immersing electrodes in an electrolyte solution (potassium chloride). Then the glass electrode and reference electrodes were dipped into the testing water sample and the pH readings were recorded.

Turbidity analysis

The turbidity of water samples was analyzed using Spectrophotometer and UV-VIS absorption, following the Nephelometric Turbidity Unit (NTU) model. The absorbance at 750 nm of both the water samples and the blank was determined using a Thermoelectron Genesys 6 UV-VIS spectrometer. The calculated absorbance value (CAV) was obtained by subtracting the blank absorbance value (BAV) from the sample absorbance value (SAV), expressed as (CAV = SAV - BAV). The turbidity (NTU value) was then derived from the scatterplot of NTU against absorbance at 750 nm.

Data analysis and results interpretation

Data obtained from this study were analysed by Statistical Package for Social Sciences (SPSS) Version 23.0 for Windows, SPSS Inc., Chicago, IL, US. Descriptive statistics were performed for interview data, while laboratory analysis (microbiological and physico-chemical) data were analysed by using paired-t- test. The significance was established at $P<0.05$. Tanzania standard (United Republic of Tanzania, 2019) of microbiological and physico-chemical limits for quality of drinking water supplies was used to interpret the results.

RESULTS AND DISCUSSION

Handling practices of the bio-sand filters

Table 1 indicates the handling practices of BSF at various households analysed in this study. About 43% (13/30) of the interviewees have attended the basic SON International seminar. According to SON International, among the criteria to get the BSF at subsidized price is to attend the basic seminar. This seminar teaches and creates awareness of beneficiaries on how to handle and operate the BSF to ensure its effectiveness and quality of water. Although most (57%) respondents did not attend the basic seminar, one among the family members should have attended the seminar as per the criteria to purchase the filter. Moreover, most of the seminar attendees were probably not involved with the upkeep and operation of the BSF. It was not clear whether they have trained other members of the households on how to operate it, therefore, improper handling and operation practices is inevitable. Moreover, follow-up by the BSF manufacturer could be inadequate to ensure that the filters are operated and well maintained. It was also evident that 92% of the analysed households got unfiltered water (direct from the source) for filtration from the public piped water supply. However, it is difficult to establish that such households would always use piped-water due to water rationing practices in the municipality. Seasonal variability in water supply is common in developing countries, particularly in Tanzania. It is possible that households experience dry taps at certain season of the year; especially during the dry seasons (summer) when water is a scarce commodity and/or when there is a technical fault in the public water supply system. For instance, several cities in the country (including Morogoro) experienced dry taps for several weeks in 2022 (Tanzania Times, 2022). During such a

Table 1. Handling practices of household-installed BSFs.

Question/practice	Category	Frequency (%)
Seminar attendance	Yes	13 (43)
	No	17 (57)
Water source	Piped water	24 (92)
	Rain water	1 (4)
	Water truck	1 (4)
Uses of filtered water	Drinking	8 (31)
	Drinking and other domestic uses	18 (69)
Treatment of unfiltered water	Sedimentation method	21 (81)
	Nothing	4 (15)
	Others	1 (4)
Cleanliness of diffuser, lid and outlet tube	Once per week	15 (57)
	Twice per week	7 (27)
	Once per month	2 (8)
	Others (rare occasion)	2 (8)
Cleanliness of sand surface	Yes	20 (77)
	No	6 (23)
Frequency of pouring water into the BSF	Once everyday	7 (27)
	More than once per day	7 (27)
	Every two days	5 (19)
	Every three days	3 (12)
	Irregular	4 (15)
Rest time for BSF / Pause period	Less than one hour	13 (50)
	One hour	1 (4)
	More than one hour	5 (19)
	More than one day	7 (27)
Filter problem	Yes	1 (4)
	No	25 (96)
Water borne diseases	Not at all	22 (85)
	Sometimes	4 (15)
Post treatment of filtered water	No any post treatment	26 (100)
BSF is an alternative water treatment method	Yes	26 (100)

situation, households may use other alternative sources like borehole, spring or open stream's water. This study observed that while majority of households (69%, Table 1) filtered water for various purposes like drinking, cooking, juice preparation, washing hands and bathing babies/infants (<1 year); a few (31%) used filtered water strictly for drinking purposes. Bio-sand filters aid removal of pathogens but also physical hazards, if households could make use of BSF to filter water for various domestic purposes like food preparation and washing utensils, outbreak of waterborne diseases in the country would have been significantly minimized or controlled.

Normally, it is expected that water from the public supply is treated and free from sediments and suspensions. However, it is not always the case at least in the developing countries including Tanzania. It is common to find sediments and suspensions in water tapped from the public water supplies. If such water is directly used in the BSF without any sedimentation process it may affect the filtration and/or cleaning schedule of the filter. In this study, it was however, observed that majority (81%) of households practiced sedimentation of water to be filtered by keeping water for some time to allow sediments to settle under gravity (Table 1). The rest (19%) did not allow water sedimentation as they believed that the filter could remove all impurities. Water from the tap may have some suspended particles which need to be removed to prevent frequent cleaning of the filter components (diffuser, lid, sand, and outlet tube). Especially during the rainy seasons, the public water filtration system could not work as intended; consequently, water from the tap may be highly soiled and contaminated. Performance of BSF is highly affected by the turbidity of unfiltered water as suspended particles will settle in the top sand layer diminishing the flow rates (Lea, 2008; Romero et al., 2020). Although majority (85%) of the households had cleaning routine of diffusers and lids, they did not have one for the outlet tubes (Table 1). The outlet tube has direct contact with external air and high chance to be touched by bare hands, yet it is the part that frequently comes into direct contact with final filtered water. When one uses highly soiled water, cleaning frequency of the BSF should be increased. However, this may always not be possible in practice taking into account of the nature of households. These practices may create chances of cross-contamination or disturb the biological layer compromising quality of filtered water.

Cleaning is very critical for the effective performance of the BSF. However, majority of the BSF users (83%) misunderstood the cleaning concept of the sand surface; the swirling and dumping process (Table 1). Thus, sand cleaning was not properly done as indicated in the operation manual. Swirling of the sand is normally performed by using a stick or finger tips which result in withdrawing of water and sand during the dumping process. As the sand is swirled within fingers, trapped dirt and dusts are dislodged from the sand and the dirty water is dumped. Then clean water is poured on the sand two to three times to get rid of the remaining dirt until clean water from the filter is observed. Moreover, all interviewed households (100%) were not aware on the required resting period of the BSF. Some households (12%) extended the resting period to 72 h (that is, 3 days), which is beyond the recommended maximum resting period of 48 h (Table 1). According to CAWST (2009) manual the pause period ranges from 1 h after the water has stopped flowing to 48 h. However, each household had at least one member who attended the basic training seminar as a prequalifying requirement. This illustrates that, the selected household members attended the training were not the ones operating the BSFs. Moreover, negligence in following the instructions (as indicated on the leaflet) could result in too little or too much pause time period, which ultimately cause exhaustion and dry out of the biological layer. This will compromise the effectiveness of the filter and quality of filtered water.

Although all visited and interviewed households in this study did not perform any other treatment of the bio-sand filtered water, the majority (85%) have never experienced waterborne diseases. Moreover, a small proportion (15%) of the households had reported a significant reduction of the frequency of falling sick as compared to before the installation of the filter (Table 1). All households were entirely dependent on the BSF filtered water for drinking and/or other domestic purposes. Use of directly filtered water from the BSF without any further treatment not only reduces costs of operation (fuel or power) but also risks of contracting chemical hazards from chemical/ ultraviolent disinfection. However, previous studies observed that although BSF significantly reduce microbiological contamination in unfiltered water (effluent) it does not meet WHO standards (<1 CFU/100 ml) for total and fecal coliforms (WHO, 2008). Therefore, to ensure this requirement, post-chlorination or boiling of the filtrate is recommended (WHO, 2008), which will prevent waterborne diseases.

Operational condition of the inspected BSFs

Eight operational parameters that a BSF must meet in order to be considered functional or active according to SON and CASWT operational manual are indicated in Table 2. These parameters were used to assess the operation of the BSF at the households. All operational BSFs (100%) were matured as they were 1-3 years in operation. A previous study reported maturity of BSF at approximately 30 days (Romero et al., 2020). Moreover, all BSFs had diffuser in good condition and properly placed. However, some (54%) BSFs had exceeded the flow rate standard limits (100-200 seconds/liter) as specified by the manufacturer. As for the required water level (that is, 4-6 cm) above the sand, it was observed that 53% of the BSFs exceeded the limit, whereas 12% of the BSFs were below the set limit. Although none of the BSF had cracks or leakages, they were dirty and foiled. Most of the operators interviewed were unaware on how to clean the outlet tube and/or whether it should be cleaned. Eventually, majority (85%) of the BSFs' outlet tubes were dirty.

Microbiological quality of unfiltered and BSF filtered water

This study also analysed the microbiological quality of unfiltered, unfiltered water and filtered water as a means to evaluate the effectiveness of BSFs. The water samples

Table 2. Operational condition of the inspected BSFs.

Parameter	Category	Frequency (%)
Bio-sand layer maturity	Matured	26 (100)
	Not matured	0
Condition of diffuser	Good	26 (100)
	Bad	0
Flow rate	Adequate	12 (46)
	Inadequate	14 (54)
Water level	Good	9 (35)
	Bad	17 (65)
Filtration sand	Fine	19 (73)
	Coarse	7 (27)
Outlet tube turbidity	Good	22 (85)
	Bad	4 (15)
Filter use	Good	20 (77)
	Poor	6 (23)
Filter leakage	Leak	0
	No Leakage	26 (100)

were collected from ten households who's BSFs met all 8 operational conditions as indicated in Table 2. When a BSF meets all 8 operational conditions, it is regarded as functional; therefore, the water samples were taken from functional filters only. The total viable count (TVC) for unfiltered water ranged from 2.2 Log CFU/ml to 2.5 Log CFU/ml, whereas in the filtered water were below the quantification limit (<1 Log CFU/ml). Previous studies have also observed high reduction of microbiological contamination in BSF filtered water (Romero et al., 2020). Although, there is no legal limit in water with respect to TVC, it is a good indicator of total quality. Also TVC estimates the total number of microorganisms like bacteria, yeasts and moulds that are likely to be present in water (Allen et al., 2004). Total viable counts observed in unfiltered water samples indicated presence of other microorganism such as bacteria, yeast or moulds that can multiply when conditions are favourable. Nonetheless, the BSFs indicated a complete removal of TVC. Use of such filters will reduce contamination and improve bacteriological quality of water. This will ultimately reduce waterborne diseases and ensure public health.

Unlike the TVC, *E. coli* (the fecal coliforms) were not detected in unfiltered, unfiltered water as well as in filtered water (Table 3). This indicated that unfiltered water was free from fecal coliforms. Unfiltered water was obtained from the public water supply, which indicated that piped water received treatments like chlorination.

According to Tanzania drinking water standards (United Republic of Tanzania, 2019), drinking water should be free from *E. coli*. Also, it illustrates that the unfiltered water was properly treated to eliminate micro-organisms including the pathogens. Nonetheless, residue chlorine in unfiltered water may kill beneficial microorganisms in the biolayer, which may cause ineffectiveness.

Although indicators of fecal contamination were below the quantification limit, total coliforms ranged from below the quantification limit to 2 Log CFU/ml in unfiltered water, whereas for filtered water sample they were from below the quantification limit (1 Log CFU/ml). Unfiltered water had high total coliforms beyond the set standards (<1 Log CFU/100 ml). However, filtered water complied with the set limits of coliforms by Tanzanian Standards of drinking water (United Republic of Tanzania, 2019). It was also observed that BSFs were very effective (100%) with total coliforms, as they were completely eliminated. A similar study reported high removal of total coliforms and *E. coli* ranging from 0.54–2.01 and 1.2–2.2 log reduction values, respectively (Romero et al., 2020). Water from the public water supply was contaminated beyond the set limit, if it could be directly drunk or used to wash fruits and vegetables as well as utensils without any intervention like boiling or BSF filtering would result into exposure of the public to microbiological hazards.

Analysis of physico-chemical quality of unfiltered and filtered water samples

The physico-chemical quality analysed in this study were pH and turbidity. These tests were done on filtered and unfiltered water samples; they were also conducted to assess the effectiveness of BSF. The pH for unfiltered water sample ranged from pH 6.5 to pH 8.5 whereas that of filtered water ranged from pH 6.8 to pH 7.7 (Table 4). The pH of unfiltered and filtered water samples complied with the set limits (6.5-8.5) for the treated potable water as per Tanzania or East African Community drinking water standard (United Republic of Tanzania, 2019; East African Standard, 2022). The pH of unfiltered filtered water was within the recommended level for the treated potable water. Low pH indicates that the water is a bit acidic, it was however, observed that filtration has slightly increased the pH. The increase in pH ranged from 0.1 to 11% among the analysed water samples. However, such change in pH did not exceed the set limits in drinking water. A study by Mangoua-allali and Coulibaly (2021) observed an increase in pH of BSF filtered water (6.15-7.49) as compared to unfiltered water (5.44-6.08). Change of pH in BSF is associated with action of micro-organisms (Holtman et al., 2022; Welz, 2024). Calcite dissolution is responsible for 95.5 ± 0.16% of the increase in pH, whereas the rest (4.5 ±0.6) is due to biotic mechanisms (Holtman et al., 2022). However, in the current study, the pH was measured at the laboratory but not point of water samples collection; this could have influenced the results.

Table 3. Microbiological quality of unfiltered and filtered water samples.

Type of water	Parameter	Mean (log CFU/ml)	Standard deviation	Minimum (log CFU/ml)	Maximum	% reduction	t-statistic	P-value
Unfiltered	TVC	1.9	1.0	0	2.9	100	5.877	0.000*
Filtered		0		0	0			
Unfiltered	*E. coli*	0	0	0	0	NA	NA	NA
Filtered		0		0	0			
Unfiltered	Coliforms	1.0	0.7	0	2	99.9	4.441	0.002*
Filtered		0		0	0			

*P-value indicating significant difference in mean log CFU/ml of TVC between unfiltered and filtered water samples. NA- not applicable; *E. coli* were below the quantification limit (in both unfiltered and filtered water samples.

Table 4. Physico-chemical quality of unfiltered and filtered water samples.

Type of water	Parameter	Mean	Standard deviation	Minimum	Maximum	% reduction	t-statistic	P-value
Unfiltered	pH	7.0	0.2	6.4	7.6	-5.96	-4.032	0.003*
Filtered		7.3		6.8	7.8			
Unfiltered	Turbidity (NTU)	7	0	7	7	14.28	NA	NA
Filtered		6		6	6			

*P-value indicating significant difference in mean pH between unfiltered and filtered water samples. NA- not applicable as there was no standard deviation (constant) in turbidity for both unfiltered and filtered water samples.

As for turbidity, all unfiltered water samples analysed had 7 NTU/100 ml whereas filtered water samples had 6 NTU/100 ml. The turbidity of unfiltered and filtered water samples was within the satisfactory limit (25 NTU/100 ml for the unfiltered potable water and 25 NTU/100 ml for the treated potable water) as per Tanzania (United Republic of Tanzania, 2019) and East African drinking water standard (East Africa Standards, 2022). However, BSF filtration indicated reduction (that is, rate of 14%) in turbidity from 7 to 6 NTU/100 ml. The effectiveness of the BSF depends on the handling practices and the operational condition of the BSF. Biological activity in BSF is time dependent, as the filter is used for long time it will mature and will subsequently increase the removal of turbidity (Romero et al., 2020). High turbidity removal rate (88%-99%) has been reported in filters depending on the filter's maturity (Romero et al., 2020). Moreover, flow rate will also determine the contact time, the longer the contact time the higher the effectiveness (Romero et al., 2020). Under the experimental set up, operational flow rate of 100 s/L was though lower and 200 s/L was higher flow rate to provide enough contact time for the filter to remove the contaminants (Baumgartner et al., 2007). A study in China observed a 20-30% removal of particulate organic carbon and more than 95% of ammonia, nitrogen, copper, cadmium and iron in rain harvested water (Liu et al., 2019).

Moreover, performance of the BSF improves with the ripening (maturity) of the biological layer. According to Elliott et al. (2008), removal of micro-organisms (for example total coliforms) by BSF increases with ripening of the biological layer. For SON, maturity of biological layer is set at 14 days from the installation but it can be extended to about one month to ensure complete maturity. Mechanism in biological layer depends on supply of oxygen and feeding from contaminated water. The set-up level for standing water above the filtration sand is at 4 cm (the lowest) and 6 cm (the highest) to allow enough supply of oxygen for aerobic microorganism. High water level prevents oxygen penetration at the bottom which results into suffocation and killing of beneficial microorganism in the biological layer (CAWST, 2009; 2012). High or low water level could be due to poor swirling and dumping process and insufficient ratio of filtration sand and gravel.

Conclusions

The present study investigated the effectiveness of Bio-sand filters as a point-of-use technology in filtering water for drinking purposes. Although fecal coliforms were below the quantification limit in both unfiltered and filtered water, BSF has indicated high effectiveness in removing TVC and total coliforms. It also reduced water turbidity and acidity by increasing pH. The BSFs have improved the microbiological quality of filtered water as it complied with the standard of drinking water. Water filtered by BSF is safe for drinking without any further treatment as most microorganisms were completely removed. However, to ensure effective filtration of water, the BSF should be well-operated and maintained.

Considering the situations in developing countries like Tanzania, this technology could be extended to all regions, especially to poor-resourced households that cannot afford other water treatment methods. This would be a solution to various waterborne illnesses, which are among the major public health challenges in the country. The charitable organization that has developed and is spreading this technology in Tanzania could be supported to reach several regions in the country. It's a power-saving technology as there is no need for further interventions after filtering. It is a relevant and cost-effective technology for the poor and areas where the supply of potable water remains a challenge.

Although the BSF is doing a good job, cross-contamination may occur if good handling practices of filtered water are ignored. Therefore, to reap the benefits of this technology, training of the households using BSF is highly recommended to ensure the right operation and maintenance of the filter. A further study is, however, recommended to assess the influence of residual chlorine on the biolayer and efficiency of the filter.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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