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Design and Development of Ceramic Water Filters for Household Drinking Water Treatment and Indicator Bacteria Removal

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ABSTRACT

Background and Objective: Contamination of drinking water is a persistent problem in developing countries like Ethiopia. Ceramic water filtration is a method that uses the advantage of a porous ceramic medium to filter microbial contaminants from water without introducing new hazards. The purpose of this study was to design and develop ceramic pot water filters from locally available materials at a laboratory scale and evaluate their performance concerning flow rate, turbidity reduction and bacterial removal efficiency from contaminated water sources. **Materials and Methods:** The volume ratios of clay to sawdust of the developed filters were 50:50, 53:47, 55:45, 60:40 and 65:35. These ratios were mixed dry thoroughly and then mixed with water to prepare a wet mix. The wet mixture was pressed in a pot-shaped container to the final shape, dried and fired at 600°C for 6 hrs in a furnace. The filters were checked for their performance concerning flow rate, turbidity reduction and bacterial removal efficiencies. **Results:** The flow rates of the 50:50, 53:47, 55:45, 60:40 and 65:35 filters were 12, 8, 6, 3 and 2 mL/hr, respectively when the water level was maintained at its maximum height. All the developed filters reduced turbidity to less than 5 NTU. Indicator bacteria were used to quantify bacterial removal efficiencies of the developed ceramic water filters. The filters removed more than 98% of the total coliform and 100% of the fecal coliform indicator bacteria from contaminated water sources. **Conclusion:** Ceramic water filters can be manufactured from locally available resources. Further investigation and scaling up of the filters are crucial to provide safe drinking water to prevent and control waterborne diseases.

KEYWORDS

Ceramic water filter, household water treatment, clay, wood sawdust, indicator bacteria

INTRODUCTION

Water is a vital resource for human survival. Safe drinking water is a basic need for good health and it is also a basic right of humans[1]. Contamination of drinking water is a persistent problem in developing countries like Ethiopia. In Ethiopia, safe water through centralized water treatment plants and piped distribution networks has been provided to urban centers for many years. However, such systems cannot be applied to rural communities due to high costs and lack of technical capabilities required for operation

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and maintenance. Thus, alternative strategies to address such problems are crucial to improve the health status of the rural community. Ceramic filters have been proven to be effective over the years and flexible in designing and making them suitable for various household needs[2].

The most commonly used household water treatment options include biosand filtration, ceramic water filters, boiling, aquatabs, solar disinfection (SODIS), PUR purifier of water and flocculants. Each of the technologies has different benefits and drawbacks; no one technology is best for everyone, rather the most appropriate technology for the user depends on several factors such as existing water and sanitation conditions, water quality, cultural acceptability, cost, availability of the technologies and local conditions. Ceramic water filters (CWFs), fabricated from locally available materials are one of the most socially acceptable household water treatment technologies due to their effectiveness, low cost and ease of use[3].

The main problem in the treatment of drinking water is to reduce potentially pathogenic microorganisms and undesirable chemicals without introducing new hazards that might pose new and different threats to human health. One promising solution may be the use of ceramic water filtration pots. The production of a clay ceramic filter for water purification offers a cost-effective and efficient means of water treatment, significantly reducing waterborne diseases[4]. Household water treatment can be a cost-effective intervention in preventing waterborne diseases[5]. One such technology is the ceramic water filter. Ceramic water filtration greatly removes bacterial contaminants from drinking water in developing countries[6].

The development of ceramic water filters is important, especially for rural areas where the settlements are scattered and people rely on surface water and shallow groundwater as a source of drinking water which are easily subjected to contamination by pathogenic microbes. Hence, this study attempted to develop ceramic pot water filters at a laboratory scale and evaluate their performance concerning flow rate, turbidity reduction and bacterial removal efficiencies using total coliform and fecal coliform indicator bacteria.

MATERIALS AND METHODS

Study area and duration: This study was conducted in Ethiopia at different areas: the raw materials used for the study were collected from the local potters and carpentry workers living in Ethiopia to design and develop the prototype for laboratory testing. The research study used laboratory work-based research that utilizes a quantitative approach. The laboratory work was carried out in the Environmental Science Program Laboratory of Addis Ababa University, College of Natural Science in Ethiopia. The design and development of the filters and laboratory testing took much time. Hence, the study was carried out over 20 months from March, 2020 to October, 2021. The duration allowed for prototype design and development, laboratory testing, extensive data collection, analysis and interpretation of the quantitative data.

Materials: Materials used include clay, grog, and wood sawdust which were mixed in different volume ratios. The clay-to-sawdust volume ratios used to develop the ceramic pot filters were 50C:50SD, 53C:47SD, 55C:45SD, 60C:40SD and 65C:35SD as quantified in Table 1. Grog is clay that has previously been fired and can be obtained by grinding clay bricks that were damaged and/or discarded after primary manufacturing. Clay was purchased from local potters. Wood sawdust was purchased from furniture centers.

Ceramic filter production process: Regardless of the type of filters manufactured, the ceramic water filter production processes follow some common steps. The process begins with material selection, preparing clay, wood sawdust, grog and water, thoroughly mixing to prepare a wet mix; followed by shaping and pressing the filter element into a desired shape using pot pot-shaped container firing and drying.

Table 1: Volume ratios of raw materials used for the developed filters

Design ratio (percent by volume) of clay to sawdust			
Clay soil	Grog/gely	Sawdust	Clay to sawdust
40	10	50	50C:50SD
43	10	47	53C:47SD
45	10	45	55C:45SD
50	10	40	60C:40SD
55	10	35	65C:35SD

50C:510SD means fifty percent clay and fifty percent sawdust by volume

The materials used in the production of ceramic pot water filters were clay, water, combustible material and grog (a non-plastic material used to reduce shrinkage and possibly to control porosity). These materials require processing such as grinding and sieving before they can be mixed into a uniform mixture that is pressed into a pot filter shape.

The process of preparing ceramic pot water filters began with the gathering of raw materials, including dry pulverized clay, a sifted combustible material with uniform particle size and clean water free of heavy metals and chemicals. These materials were thoroughly mixed using a mixer, starting with the dry ingredients, followed by the uniform addition of water to create a smooth clay mixture. The mixture was then blended for at least ten more minutes. The clay was divided into blocks of approximately 8 kg each. Each block was molded into a pot shape using a hydraulic press and the outer surface of the pressed filter was smoothed with a plastic scraper to ensure an even texture and sturdy rim. Each filter was then labeled with a unique stamp or number.

The filters were dried in the shade for three to four hours to begin hardening, then placed on drying racks for 7 to 18 days, depending on the weather condition, to remove excess moisture that could cause cracking during firing. The filters were carefully arranged in the kiln, ensuring they did not touch each other, allowing for uniform heat distribution. The kiln temperature was gradually raised to 100°C over 2 hrs to remove any remaining moisture and then increased to around 900°C to facilitate vitrification, where silica and alumina molecules in the clay melted and bonded, altering the chemical structure of the clay.

Once the firing process was complete, the filters were allowed to gradually cool, first inside the kiln for about 24 hrs, then transferred to drying racks to continue cooling. Silver was added to the filters as a chemical barrier to bacteria, using a solution made from either silver nitrate or colloidal silver, with concentrations varying based on the purity of the silver. The solution was either painted onto both the inside and outside of each filter or the filters were submerged in the solution.

Ceramic pot filter development: Ceramic pot water filters were designed and developed by combining different volume ratios of clay soil, grog/gely and wood sawdust as in Table 1. The combinations of raw materials were selected after testing several ceramic pot water filter preparations which were prepared with different ratios of clay/grog/sawdust.

Ceramic pot water filter development process: The filter development process includes grinding clay and wood sawdust to create a fine powder.

Consistency in the powder was obtained by sieving using a 30-mesh sieve size. The powders were dry mixed until a uniform mixture was formed and then mixed with water. The wet mixture was kneaded for shaping to obtain the desired shape of the filter. After shaping, it was dried and fired to burn out the combustible material.

Process description: Sieving the clay and combustible material was the first step and important to ensure that the pores in the final product were the appropriate size. The sieved material was then placed into a container for mixing.

The same process was used for the combustible material to ensure particle size consistency in the mix. Once the dry materials had been sieved, the powders were ready for the preparation of the dry mix. The proportions of the clay to the combustible material were crucial in determining the right "plasticity" and final flow rate of the filter.

Water was added to the dry ingredients that had been thoroughly mixed. The amount of water typically added to the mix was approximated so that the mix was not too wet or too dry for shaping. When the wet mix was prepared, it became a moist lump of clay. After this step, the clay was wedged to get further work in the moisture and get all of the air out of the mixture. Wedging consists of folding the clay over upon itself repeatedly and applying pressure. After wedging, the mix became consistent, air-free and a lump of moist clay. After shaping, the filters were ready to air dry. The purpose of drying was to remove as much moisture as possible before the filters were placed into the furnace. If the filters have excessive moisture, the water evaporates inside the clay when we fire it and causes the filters to explode.

The filters were placed in a dry area for four to five consecutive days. Clay to sawdust volume ratios of 50C:50SD, 53C:47SD, 55C:45SD, 60C:40SD and 65C:35SD were used to develop the ceramic pot water filters. The dried-out, prepared ceramic pot water filters were placed in the furnace to be vitrified. This is a critical step in the development of the filters. After the filters were cooked, the furnace was allowed to cool slowly until the filters could be handled by hand. Five different ceramic pot water filters with different clay-to-sawdust volume ratios were developed and tested for flow rate, turbidity reduction and indicator bacteria removal efficiency using contaminated water sources.

Filter performance testing: Before and after treatment, water samples were analyzed to determine the filtration performance of the developed filters. The filter performance testing was based on the flow rate, turbidity reduction and pathogen removal efficiency.

Flow rate: The flow rate test was conducted using low turbidity tap water to eliminate the effects of the particulate clogging the filter pores and approximately measured by measuring volume of water filtered while recording the time required flowing out. The ceramic water filters should be wetted or soaked in water for 24 hrs before the flow rate test to saturate the filters and also to remove any remaining ashes of the combustible material.

Ceramic water filter performance in terms of flow rate can be described by Darcy's Law[7] for flow across a porous material. This mathematical model helps to conceptualize and anticipate how changes in parameters such as surface area or filter thickness affect the flow rate. The flow rate in turn can be used as a simple proxy to evaluate filter performance in terms of microbial removal. If the flow rate is very high then it is likely that the filter is too porous to provide proper removal of bacteria and if it is too low then it is simply impractical in terms of supplying enough water to a typical household. It is important to realize that flow rate is not necessarily a measure of pathogens removal, but rather an indicator of water flow-through and possible ease with which bacteria-size particles could flow through the filter.

The flow rates were measured by taking the volume ratio of water measured in the plastic container to the time taken for which the volumetric measurement was taken[8]:

$$\text{Flow rate} = \frac{\text{Volume of water measured at time (t) (mL)}}{\text{Elapsed time, t, from the start of the test (hour)}}$$

Turbidity: Water samples used for the experiments were from a river where the communities use the water sources for domestic purposes. Influent and effluent water samples were tested for turbidity. Initially, the water was tested for turbidity before being filtered. Water was then passed through the filters. The filtered water was then tested for turbidity reduction by the developed filters.

Detection of pathogens: The filters were tested for the removal efficiencies of microbiological parameters (total coliform and fecal coliform). Microbial indicators (total coliform and fecal coliform) in influent and effluent water samples were analyzed by 100 mL membrane filtration technique using 0.47 mm diameter and 0.45 µm pore-size membrane filters following standard methods[9]. Total coliform was quantified using membrane filtration (MF) techniques followed by incubation at 37°C for a minimum of 14 hrs following 4 hrs resuscitation on Membrane Lauryl Sulphate Broth (MLSB). For the fecal coliform, the same procedure and materials were used except for the incubation temperature, which was at 44°C. In both cases, the colony-forming unit was counted by the use of low-power magnification lenses and reported as a colon-forming unit (CFU) per 100 mL.

Filter bacterial removal efficiency: Microbial removal efficiency was calculated in terms of percent removal efficiency[10]:

$$\text{Removal efficiency (\%)} = \frac{\text{Cinfluent - Ceffluent}}{\text{Cinfluent}} \times 100$$

Where:

$C_{influent}$ = Microbial concentration in the raw water sample (CFU/100 mL)

$C_{effluent}$ = Microbial concentration in the filtered water sample (CFU/100 mL)

RESULTS AND DISCUSSION

Quantity of water filtered: The quantity of water filtered was measured for the developed ceramic pot water filters as shown in Table 2. By filling the filters with water to the top (maximum height) the quantity of water filtered from each of the 50C:50SD, 53C:47SD, 55C:45SD, 60C:40SD and 65C:35SD filters was 12, 8, 6, 3 and 2 mL, respectively for the first 1 hr and increased with time. Among the developed five ceramic pot water filters, the quantity of water filtered was maximal for the filter developed from 50C:50SD while it was minimal for the filter developed from 65C:35SD. This reveals that as the ratio of clay to sawdust increases less water drips from the filter.

Table 2 shows the increase in the quantity of water filtered from each of the developed filters over time. However, the flow rate decreases when the time increases as water pressure and gravity are the deriving forces. Not only the need to improve access to safe drinking water is recognized, but also the problem of a lack of sufficient quantities of safe drinking water needs attention. If a family or community decides to invest their resources into a water treatment system, it is important that they not only get water that is free of harmful bacteria and disease-causing pathogens but also available in sufficient quantities to meet their needs.

A water treatment system that provides safe drinking water is virtually useless if there is not enough quantity of it. It is difficult to make accurate estimates regarding daily fluid intakes because the requirement is highly dependent on body physiology, activity level and local climate. An average estimate based on a review of the literature for adult males is 2.9 L/person/day, adult females are 2.2 L/person/day and children are 1.0 L/person/day[11]. If properly scaled up and manufactured, the developed ceramic pot water filters are capable of producing sufficient safe drinking water for an average five-member household. This is assuming the situation where the filter is consistently refilled throughout the day (to maintain the maximum level of hydraulic head). Taking the above issues into consideration, it will be important to scale up and evaluate whether ceramic pot filters are providing safe and sufficient water quantity in the field.

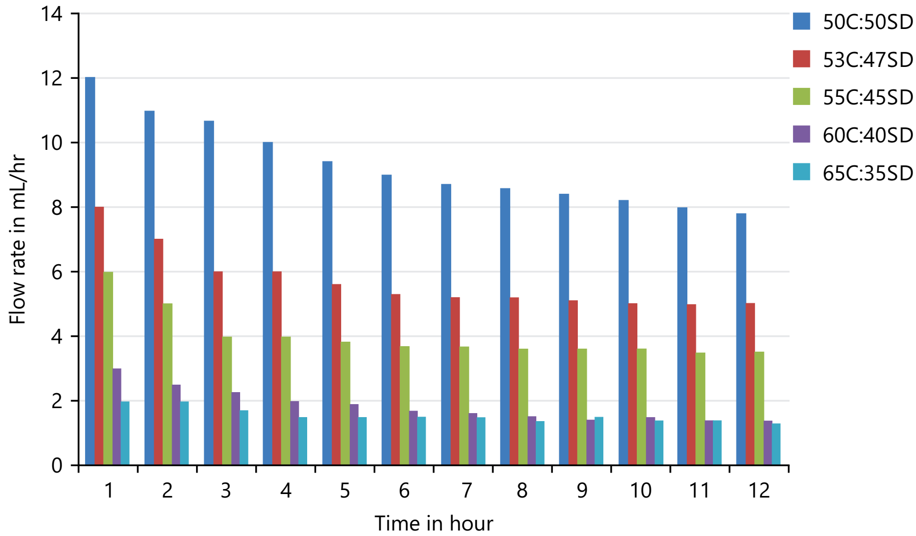

Fig. 1: Flow rate of the developed ceramic pot filters

Table 2: Quantity of water filtered in mL from each of the filters for each time interval

	Quantity of water filtered in mL after											
Design ratio	1 hr	2 hrs	3 hrs	4 hrs	5 hrs	6 hrs	7 hrs	8 hrs	9 hrs	10 hrs	11 hrs	12 hrs
50C:50SD	12	22	32	40	47	54	61	69	76	82	88	94
53C:47SD	8	14	18	22	28	32	38	42	46	50	55	61
55C:45SD	6	10	12	16	19	21	24	29	33	36	39	43
60C:45SD	3	5	7	8	9.5	10	11	12	13	15	16	18
65C:35SD	2	4	5	6	7.5	9	10	12	13	14	15	16

Findings of flow rate: Flow rate is an important factor to be considered in determining the performance of ceramic water filters. A higher flow rate means that the porosity of the filter is high with a larger pore size, letting more impurities pass through the filter. Thus, the flow rate of a filter is often inversely related to the contaminant removal efficiency.

The results of the study showed that the developed ceramic water filters have maximum flow rates of 12, 8, 6, 3 and 2 mL/hr for clay-to-sawdust combination ratios of 50C:50SD, 53C:47SD, 55C:45SD, 60C:40SD and 65C:35SD respectively when the filters were filled with water (Fig. 1).

One approach to increase the flow rate was to increase the number of pores in the filter by raising the proportion of sawdust to clay. If there are more pores in the filter, then water should flow through the filter faster. The study results revealed that as the percentage of sawdust increased the flow rate also increased. A difference in flow rate between the filters made with 50 and 35% sawdust was observed.

This shows as the proportion of clay to sawdust increased, the flow rate decreased. Another observable trend from the flow rate tests performed was that the flow rate decreased with time for all the filters tested. This trend is expected as pressure due to water is the driving force in the filtration mechanism. Because the filters are shaped like a pot and water is primarily filtered through the sides of the filters, it is expected that a more full pot (more water contact area) would filter water quicker than a less full pot[11]. Furthermore, when the pot is full, there is a greater pressure head in the filter, which facilitates the filtration. This finding was consistent with the results of the research conducted in southern Ethiopia[9] and in Nigeria.

As can be seen from Table 3, laboratory test results indicated that the developed ceramic water filters are capable of removing more than 98% of the total coliform bacteria and 100% of the fecal coliform from influent water samples. Many studies assessing the performance of ceramic water filters have found them

Table 3: Total coliform (TC) and fecal coliform (FC) in source and filtered water samples

	Raw water		Filtered water		Removal efficiency	
Design ratio	TC (CFU/100 mL)	FC (CFU/100 mL)	TC (CFU/100 mL)	FC (CFU/100 mL)	TC (%)	FC (%)
50C:50SD	760	72	12	0	98	100
53C:47SD	760	72	12	0	98	100
55C:45SD	760	72	6	0	99.2	100
60C:40SD	760	72	2	0	99.7	100
65C:35SD	760	72	0	0	100	100

Table 4: Some physical parameters in source and filtered water samples

		Filtered water from				
Parameter	Source water sample	50C:50SD	53C:47SD	55C:45SD	60C:40SD	65C:35SD
Turbidity (NTU)	9	<5	<5	<5	<5	
PH	7.8	7.4	7.2	7.1	6.9	6.8
Temperature (°C)	22.8	22.6	22.5	21.8	21.6	21.5
Conductivity (μs)	308	164.8	138	134	108	103

to be highly effective in removing total and fecal coliforms from bacterially contaminated water sources[12]. The ceramic water filter technology should remove 99.98% of total coliform and *E. coli* under laboratory conditions[13]. Some other studies revealed that the effectiveness of ceramic water filters at removing bacteria, viruses and protozoa depends on the production quality of the ceramic filter. Most ceramic water filters are effective at removing most of the larger protozoan and bacterial organisms, but not at removing the smaller viral organisms[14]. Studies have also shown that pathogenic bacteria are removed from contaminated water sources by filtering the water through high-quality locally produced ceramic water filters in developing countries[15]. The coliform group of organisms is the most widely used indicator organisms for water quality testing.

Fecal coliform, a subset of the total coliform group is associated with the intestinal tract, whose presence in water indicates that the water has received contamination of an intestinal origin. In testing the microbial quality of water, indicator organisms were used to test the microbial removal efficiency of the filters. Total coliform and fecal coliform indicator organisms are typically microbes that do not cause disease by themselves but are found in harmony with waterborne pathogens in higher concentrations.

These common indicator organisms are so numerous in fecal matter and testing them is carried out more easily with less expensive equipment[16]. The presences of coliform organisms have health significance for consumers and have a recommended value of zero CFU/100 mL.

Turbidity reduction test: Following filtration, the turbidity of the treated water was reduced to less than 5 NTU for all the developed ceramic pot filters tested as in Table 4. This level is within the acceptable drinking water quality standards of 5 NTU as set by the World Health Organization. 50C:50SD has highest pH, temperature and conductivity as well.

The inflow water from the river water source was found to have turbidity levels varying between 7 and 12 NTU with an average of 9 NTU. Even when raw water with higher turbidity levels was used, the turbidity of the treated water was found to be below 5 NTU. The developed ceramic water filters have the capability of reducing turbidity to less than 5 NTU. Turbidity is a water quality parameter that quantifies the degree to which light traveling through a water column is scattered by the suspended organic and inorganic particles. The scattering of light rays increases as the suspended load increases. Turbidity is commonly measured in Nephelometric Turbidity Units (NTU).

Organic constituents in water may harbor microorganisms and thus water with high turbidity generally has a higher concentration of pathogens and a higher possibility of transmitting waterborne diseases.

Studies have shown that there is a strong relationship between the reduction of turbidity and the removal of pathogens in the water filtration process[17]. Additional parameters tested to characterize source water included conductivity, temperature and pH. Results of the analysis of pre- and post-filtration of the water samples showed some interesting indications. Both pH and conductivity of the filtered water were decreased. These may be due to the entrapment of some ions within the filter element by clay.

Parameters that affect filter performance: One of the major factors that affect the filter performance is the ratio of sawdust to clay. If the volume ratio of sawdust is increased, more pores are created in the filter and water likely flow through the filter at a faster rate. This could compromise the filter's ability to remove pathogens from contaminated water and also two or more pores become connected allowing for the passage of larger particles. However, the filter becomes more fragile and less solid if it is composed of a higher proportion of pores. It is important to avoid compromising the durability of the filter because breakage is a main factor of filter disuse[18].

The size of the pores is important in controlling the flow rate and the level of contamination removal of the filter. Filters with a small pore size are efficient at removing turbidity and bacteria from contaminated water. However, the flow rate increases as the filter pore size increases. Filter thickness affects the ceramic water filter flow rate. With a thin ceramic device, the flow rate increases but the level of water microbiological and turbidity removal decreases. By increasing the thickness the filter removes more pathogens and other particles. The surface area has a major impact on the filter performance. A larger surface area of the ceramic element allows more water to flow through the filter. The surface area can be increased by increasing the radius of the filter.

The height of the water above the filter affects the flow rate. Greater fluid pressure or hydraulic head is a function of the height of water in the filter. The more pressure on the filter element and thus the more flow through the pores in a given period. While, the water height decreases with time in the filter, the water pressure becomes smaller and therefore less water flows through the filter. It is therefore important to maintain a certain level of water head in the filter by filling the filter to its top with water.

In general, increasing all of the above parameters except for the filter thickness increases the flow rate. Increasing the filter thickness decreases the flow rate. The flow rate increases faster for an increase in surface area since the flow rate is proportional to the diameter squared.

Water turbidity affects the ceramic water filter flow rate. Water containing high organic content and/or many suspended particles slow down the flow rates of water by progressively clogging the ceramic pores. This affects the quantity of filtered water collected.

Comparisons of ceramic water filters: Ceramic filters have micro-scale pores that are effective for removing bacteria from water. The filter sare made from clay that is often mixed with materials such as sawdust or wheat flour to improve porosity. There are three main types of ceramic filters: Disk, candle and pot filters with multiple variations of each.

A disk filter consists of a removable ceramic filter sandwiched between two containers. Candle filters consist of one or more candle-shaped ceramic filters and two chambers while pot filter consists of only one plastic or ceramic receptacle. The three filters are compared concerning contaminant removal, quantity of water filtered, ease of use and cost. Disk and candle filters are generally effective for removing turbidity, iron, coliforms, fecal contaminants and *E. coli* from contaminated water. In studies, disk filters with colloidal silver have exhibited a 93 to 100% bacterial removal rate and those without silver have shown an 80% removal rate. Candle filters with colloidal silver generally exhibit 100% bacterial removal and those without silver average 85% removal. Disk filters range from 83 to 99% turbidity removal. Pot filters remove 98% of total coliform and 100% of fecal coliform and reduce turbidity to less than 5 NTU. Hence, pot filters are better than disk and candle filters concerning bacterial removal efficiency.

In general, ceramic water filters are not effective for removing organic contaminants. Disk filters typically have a flow rate of 1 to 11 L/hrs candle filters have a flow rate of 0.3 to 0.8 L/hrs while pot filters have a flow rate of 1 to 2 L/hrs. Under conditions where the filters are continuously refilled, a filter with a flow rate of 1.5 L/hrs would provide about 7 L/day per person for a family of five.

Ceramic water filters are easily assembled and no component construction is required of the user other than placing the filter into the container. The ceramic pot filter is assembled as one complete unit, unlike disk and candle filters. Scrubbing the filter with a toothbrush is required as maintenance. The production of ceramic filters is an easy process that doesn’t require advanced technology. Ceramic pot water filter production is the easiest of all because it can be produced locally using local knowledge and local materials. This contributes to their relatively low price of 12-25 USD, which varies depending on the region and the resources available. The quality of the filters can be affected by variations in clay composition across geographic regions.

Disk filter units cost about US$3.50 and replacement filters range from US$0.49 to $1.02. Disk filters need to be replaced every 5 years. Candle filter units cost about US$2.29, with replacement filters averaging about US$0.46. Candle filters need to be replaced every 6 to 12 months. For ceramic pot water filters additional labor and maintenance costs are minimal.

CONCLUSION

The developed ceramic pot water filters were able to remove more than 98% of the total coliform and 100% of fecal coliform indicator bacteria from the contaminated water sources. Household water treatment and safe storage, as an option, should be an integral part of the drinking water treatment and sanitation strategy. Preliminary development and laboratory test results of the ceramic pot water filters showed promising results, but more research is required to make the filters applicable at large scale.

SIGNIFICANCE STATEMENT

Contaminations of drinking water have led to the design and development of various drinking water treatment technologies. The design and development of ceramic filters are important for rural areas of low-income countries. The technology of using ceramic filters is simple, affordable and utilizes local materials and traditions, yet has not been implemented in rural areas of Ethiopia. The designed and developed filters reduced turbidity to less than 5 NTU and removed 98% of the total coliform and 100% of the fecal coliform indicator bacteria from contaminated water sources. The development of the filters addresses critical public health challenges associated with waterborne diseases. It also contributes to scientific knowledge by advancing filtration technology, understanding microbial removal mechanisms, promoting sustainability and advancing sustainable development goals.

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