Tanzania Journal of Science 51(1): 169-181, 2025
ISSN 0856-1761, e-ISSN 2507-7961

Exploring the Efficiency of Ceramic Water Filters towards the Removal of Selected Contaminants in Tanzania

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Received 15 Mar 2024 Revised 24 Oct 2024 Accepted 26 Feb 2025 Published 14 April 2025
https://dx.doi.org/10.4314/tjs.v51i1.12

Abstract

The current study explores comparatively the efficiency of common ceramic water filters (CWF) in removing selected contaminants in water samples collected from rivers and ponds. Pot type (CWF1) and candle type (CWF2) ceramic water filters were purchased from the market to explore their efficiency towards removing organic matter, *E. coli*, turbidity, total suspended solids and colour in different retention times. The results on the quality of water from river and pond revealed that the levels of contaminants in water exceeded the standard set by TBS and WHO. The ability of CWF1 for organic matter removal in water from Kwakilosa river was 50% and Kalenga pond was 58%. On the other hand, the ability of CWF2 for organic matter removal in water from Kwakilosa river and Kalenga pond was 100%. *E. coli* removal for CWF1 was 84% for water from Kwakilosa river and 93% for water from Kalenga pond. For CWF2 dosing experiments *E. coli* removal efficiency was 100% for water from Kwakilosa river and 98% for water from Kalenga pond. In the third run, the CWF2 achieved a maximum *E. coli* efficiency removal of 100%. The study concluded that ceramic water filters that are found in Tanzania market are effective in removing specific water contaminants. However, CWF2 was more efficient than CWF1 due to the presence of activated carbon inside the filter. This study suggests that the ceramic water filters that available in the market should be modified to remove multiple contaminants.

Keywords: Ceramic Water Filters; Water Contaminants; Water treatment; Organic matter; *E. coli*

Introduction

According to the World Health Organization (WHO), drinking water is a basic human right (Farrow et al. 2018). Access to safe and clean water has been a challenge in the world (Abd-Elaty et al. 2021). Approximately 1.2 million people lack access to safe drinking water (Salehi 2022, Mishra 2023). For instance, 85% of world urban population could access safe and clean water that is free from contamination, the percentage of rural areas is only 53% (Yang et al. 2020). This shows that large effort is needed in rural areas where contamination of drinking water is the great threat to human health (Yang et al. 2020, Mishra 2023,). Inadequate access to safe and clean water is a major cause of waterborne diseases (Nwabor et al. 2016; WHO 2019). There are many water resources used by people in the world which are not safe for human health hence making people vulnerable to waterborne diseases (Akosile et al. 2020). Additionally, contamination of surface and groundwater significantly contribute to the spread of waterborne diseases among people (Martins et al. 2016; Manetu and Karanja 2021). Water contamination is caused by different sources such as sewage, industrial, municipal waste, hazardous waste, manufacturing waste and medical waste (Nahiun 2021). The 2030 Agenda for Sustainable Development goal number six is to ensure adequate global water supply (Irannezhad et al. 2022). Several efforts have been made by governments, non-government organizations (NGOs) and water projects to provide safe water to the people but waterborne diseases persist (Ahmed et al. 2020; Hutton and Chase 2016). The 2019 United Nations (UN) report revealed that 2.2 million people died as a result of waterborne diseases, with the majority of them being children under the age of five (Shayo et al. 2023), This is a common problem in developing countries, and it is exacerbated in rural areas (Hutton and Chase 2016, Shayo et al. 2023).

Water resource management and access to safe and clean water is becoming a serious concern in developing countries (Chirisa et al. 2017, Mishra et al. 2021). For example, municipalities supply safe water for domestic use, however, in developing countries there are inadequate municipal water supply systems (Brown et al. 2008, Komba et al. 2022). This makes people use water from various sources such as rivers, ponds and streams. For example, around 16 to 20.5 millions of Kenyans travel long distances for searching water from such sources (Henry et al. 2013; Maingey et al. 2022). The need for clean and safe water forces people to look for convenient and affordable water treatment technologies (Solomon et al. 2023). On the other hand, the issue of water treatment technologies in developing countries has been a problem (Garrido-Cardenas et al. 2020). The use of effective water treatment technology to purify water so as to obtain drinkable water is also a challenge leading to the existence of persistent waterborne diseases (Garrido-Cardenas et al. 2020, Rehman et al. 2021). The use of ceramic water filters (CWFs) can be one of the solutions to reduce waterborne diseases (Henry et al. 2013). CWFs are widely used due to their low cost, effectiveness and ease of use (Yang et al. 2020). They have also been used to ensure quality water provision in several countries such as Bolivia, Cambodia, China, Dominican Republic India, Ethiopia, Nigeria and Sri Lanka (WHO 2019, Salehi 2022). CWFs have also been reported to reduce diarrhea in countries such as Columbia (60%), Bolivia (75%) and South Africa (80%) (Shepard and Oyanedel-Craver 2022, Alford et al. 2023).

To date, various water treatment technologies have been developed in Tanzania to purify water from different sources such as rivers, ponds and streams. The most common water filters found in Tanzania markets are ceramic water filters, bone char filters, bio sand-filters, slow sand filters, and membrane purifiers (Salehi 2022, Alford et al. 2023). Among them, ceramic water filters are less expensive technology designed specifically for improving water quality (Soliman et al. 2020, Solomon et al. 2023). Previous reports also show that ceramic water filters are a more effective technology than other household water treatment and safe storage (Rivera et al. 2020, Soliman et al. 2020, Tariq et al. 2020, Alford et al. 2023). Therefore, this study aimed to evaluate the efficiency of ceramic water filtration systems available in the Tanzania market in the quest to reduce waterborne diseases.

Materials and methods

Study Site

Water samples were collected from two areas namely Kwakilosa river and Kalenga pond located at latitude 7°46’30.54612 S and longitude 35°36’0.65812 E and latitude 7°46’3.04588 S longitude 35°39’30.09788 E, respectively. Kwakilosa river is located at Iringa municipal, about 1601 m above sea level while Kalenga pond is located in Iringa rural district about 1500 m above sea level as indicated in Figure 1. The areas are well known for agricultural activities such as farming and livestock keeping. Analysis of water parameters such as pH, temperature, total suspended solids (TSS) and conductivity was done in sampling sites. Other parameters such *E. coli*, colour, turbidity, organic matter and heavy metals were analyzed in the Department of Chemistry laboratory at Mkwawa University College of Education (MUCE) and Iringa Urban Water Supply and Sanitation Authority (IRUWASA) laboratory.

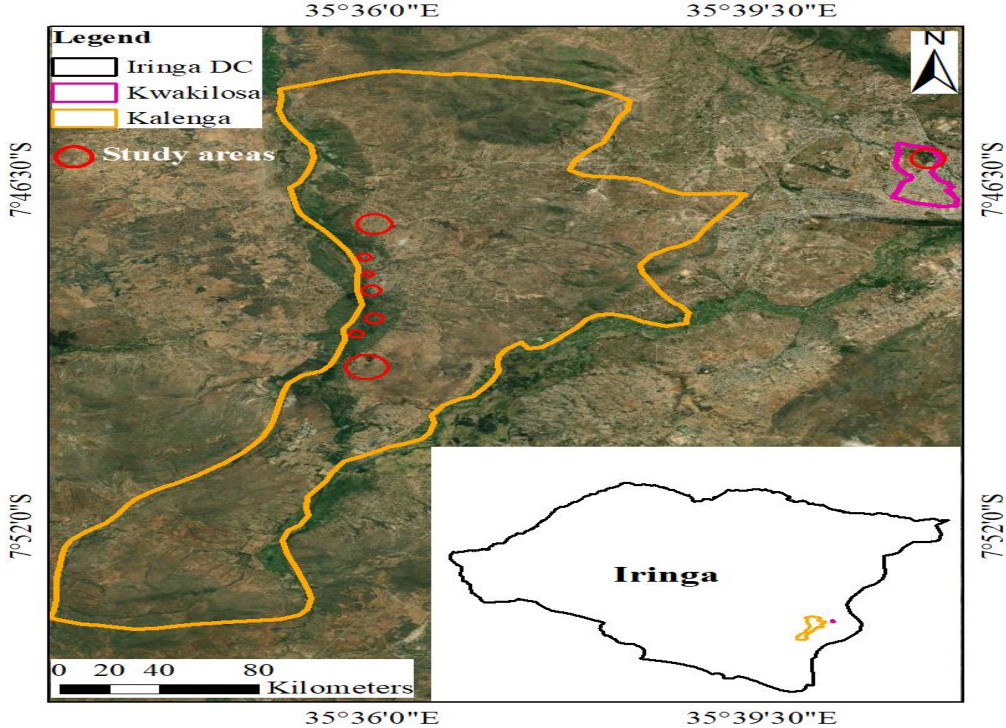

Figure 1: A Map of the Study showing the Sampling sites (a) Kwakilosa river (b) Kalenga pond

Materials

Before purchasing water filters for various experiments, a market survey was conducted in Iringa town to identify the most commonly used ceramic water filters. Pot type and candle type were observed to be common ceramic widely used. Thus, pot type ceramic water filter 1 (CWF1) and candle type ceramic water filter 2 (CWF2) were purchased from the market. For comparison purposes, the ceramic water filters from the market were evaluated for their abilities to remove physical, chemical and biological impurities.

Collection of Water Samples

Sampling points were selected such that the samples taken were representative of different sources from which water is obtained by the public. For the effective investigation of water parameters, sampling points in the study areas were the areas where there was pollution caused by livestock farming and irrigation activities. Water samples were collected in sterile plastic bottles such that their neck was below the water surface so as to avoid the inclusion of atmospheric oxygen which could purify water. Water parameters such as pH, total suspended solids (TSS), conductivity, and temperature were measured on-site during sampling. The collected water samples were carried in a cool box to the MUCE Chemistry Laboratory for analysis. Two drops of diluted nitric acid (125 g/L) were added to 2 L of water samples from each site to convert heavy metal ions into their nitrate salts for easy detectability during analysis. Then water samples were kept in the refrigerator at 4 °C to maintain the integrity of the sample.

Analysis of Physical, Chemical and Biological Water Contaminants

Physical parameters analyzed were temperature, colour and turbidity. Temperature was determined by a mobile thermometer, while colour was determined by the spectrophotometer and turbidity was measured by a turbidity meter. The measured biological parameters were *Escherichia coli* (*E. coli)* and Biological Oxygen Demand (BOD_5). Water samples were cultured in 3 discs for about 24-72 hours. Then, the amount of *E. coli* in the filtered water was determined by membrane filtration method and BOD_5 was analyzed by OxiTop. Chemical parameters which were measured were conductivity, Total Suspended Solids (TSS) and heavy metals such as Zn, Mn, Pb, Cu, Ni, and Cr. The pH of the sample was determined using a pH meter. Heavy metals were determined by using DR 1900 Colorimeter. Conductivity and TSS were analyzed by conductivity meter. All these parameters were analyzed before and after filtering using common ceramic water filters.

Evaluation of Efficiency of Common Water Filters Under Varying Retention Times

To determine the efficiency of water filtration systems, 30 L of water samples were introduced to the water filtration systems in a batch. Different retention times ranging from one to three days were applied to treat water samples with known characteristics of water contaminants. Efficiency of common ceramic water filters were determined using equation (1).

$$E = \frac{Co - Cf}{Co}\, x\, 100\% \ldots (1)$$

Where E is the efficiency of water filtration systems, C_o is the initial concentration of a certain parameter, and C_f is the final concentration of a certain parameter.

Data Analysis

Descriptive statistics were employed to describe the water quality testing results obtained from laboratory and field samples. This analysis included a normality test with a 95% confidence interval, a mean, and a standard deviation. Parametric statistical tests were used to compare results. A t-test was employed for statistical comparisons between the obtained data using a significant level of $p \leq 0.05$ at 95 confidence interval. Graphs were drawn using Origin Pro Lab version 8.6, which aided in determining the efficacy of common water filters.

Results and Discussion

Physical, Chemical and Biological Contaminants of Water from Kwakilosa river and Kalenga pond

Potable water is clean, safe, and free of physical, chemical, or biological pollutants. Water from natural sources usually contain physical, chemical and biological contaminants that can pose a serious health problem to users. The results on physical, chemical and biological contaminants of water are presented in Table 1. Table 1 indicates that water from Kwakilosa river and Kalenga pond contained various contaminants. The highest level of biological contaminants such as *E. coli* in water from Kwakilosa river can have serious problems to human health such as severe stomachache, vomiting and diarrhea as well as urinary tract infection (UTI). The highest level of conductivity in water lacks direct health impacts to the users but it can affect the quality of water. The high level of colour in water does not pose any health risk to the users although water that looks dirty is not readily acceptable for drinking. It can further be seen that the level of turbidity in water collected from Kwakilosa river and Kalenga pond exceeded the standards set by Tanzania Bureau of Standards (TBS) and WHO as shown in Table 1. The high level of turbidity can be due to the presence of sediment or organic contaminants. TSS from Kwakilosa river also exceeded the standard set by WHO. The levels of BOD_5 and heavy metals such as Mn, Cr, Cu, Zn, and Pb for water from Kalenga pond exceeded the standard set by both TBS and WHO. The high level of heavy metals in water can pose health risks to human such as cancer, anemia, intestinal damage also it can affect body organs such as liver and kidney. Chemical contaminants such as total dissolved solids and heavy metals can enter water through waste water and industrial effluents. These factors give water an unpleasant odor and colour, making it aesthetically unacceptable to humans (Sado-inamura and Fukushi 2018, Tariq et al. 2020). Turbidity in water has reportedly to be caused by chemical precipitates, organic silt, bacteria and other germs (Nzung 2019; Sarma 2020). Therefore, water from Kwakilosa river and Kalenga pond is not safe to users due to presence of various contaminants which can pose serious health problems.

Table 1: Levels of Physical, Chemical and Biological Contaminants of Water from Kwakilosa river and Kalenga pond

Water parameter	**Average water values**		**Standards of water quality**	
	Kwakilosa river (Mean ± SD)	**Kalenga pond (Mean** ± SD)	**TBS (2010)**	**WHO (2017)**
pH	7.85 ± 0.03	7.53 ± 0.02	6.8-8.5	6.5-9.2
Conductivity (µS/cm)	1013.0 ± 43.44	158.0 ± 20.35	1000.0	120.0
TSS (mg/L)	507.0 ± 40.32	52.0 ± 0.01	100.0	-
Turbidity (NTU)	8.56 ± 2.05	262.3 ± 3.14	25.0	5.0
Colour (Pt.Co)	74.66 ± 3.18	80.7 ± 4.21	5.0	6.0
BOD_5 (mg/L)	3.33 ± 0.01	18.67 ± 0.37	6.0	6.0
E. coli (CFU)	892.5 ± 88.47	58.67 ± 2.12	-	-
Cr (ppm)	0.40 ± 0.18	0.33 ± 0.12	0.05	0.05
Cu (ppm)	3.40 ± 0.10	4.0 ± 0.09	3.0	2.0
Mn (ppm)	0.20 ± 0.01	0.6 ± 0.11	0.5	0.4
Zn (ppm)	7.50 ± 0.54	6.0 ± 0.45	5.0	5.0
Pb (ppm)	0.20 ± 0.01	0.10 ± 0.01	0.01	0.01
Ni (ppm)	-	0.30 ± 0.02	0.20	0.07

SD = Standard deviation

Efficiency of Ceramic Water Filters in Removing *E. coli*

Figure 2 depicts the results on *E. coli* removal from natural water experiments by using CWF1 and CWF2. In the first run (one-day retention time) of CWF1 dosing experiments, removal efficiency was 84% for water from Kwakilosa river (Kw) and 93% for water from Kalenga pond (Kn). The difference in removal efficiency might be caused by the difference in concentration of *E. coli* between Kwakilosa river and Kalenga pond. The high concentration of *E. coli* in water from Kwakilosa river caused the filter to pass some *E. coli*. For CWF2 dosing experiments removal efficiency was 100% for water from Kwakilosa river and 98% for water from Kalenga pond. In the third run (day three (3) retention time) the CWF2 achieved a maximum *E. coli* efficiency removal of 100%. The comparison mean of CWF1 and CWF2 towards *E. coli* removal was statistically significant with p values less than 0.05 ($p \leq 0.05$) using a paired sample t-test at 95% confidence interval. CWF1 and CWF2 had higher rates of microbial removal with p value of 0.04. From the findings it was noted that CWF2 is more efficient than CWF1 in removing *E. coli*. It is suggested that CWF1 has larger pores which allow the passage of microorganisms compared to CWF2. The series on the improvement in *E. coli* reduction over a course of the batch experiments are shown in Figure 2.

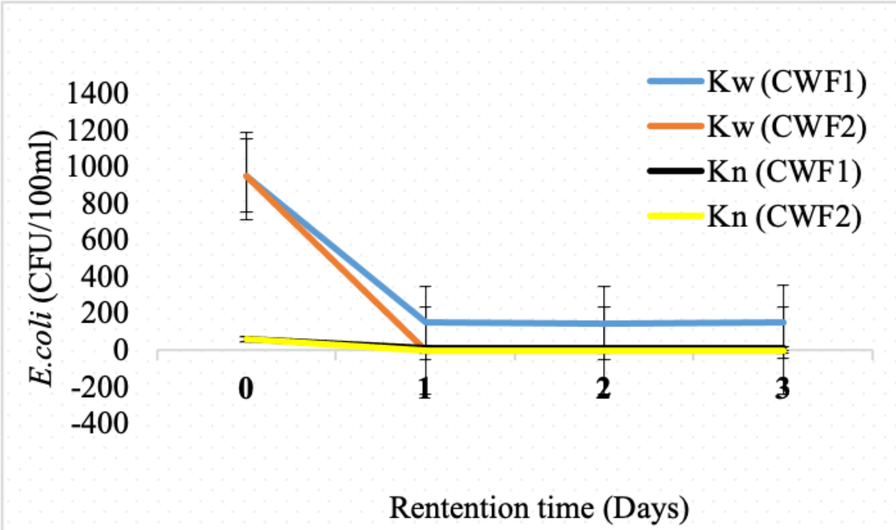

Figure 2: Concentration of *E. coli* as a function of retention time for filtration of water samples from Kw and Kn through CWF1 and CWF2.

Efficiency of Ceramic Water Filters towards Turbidity Removal

Figure 3 depicts the ability of the water filters to remove turbidity. The results from the first run (one-day retention time) showed that the efficacy of CWF1 in turbidity removal for water from Kwakilosa river was 96% and for water from Kalenga pond was 96%. It can be seen that for CWF2, the turbidity removal for water from Kwakilosa river was 98% and for water from Kalenga pond was 99%. The ability of both CWF1 and CWF2 in removing turbidity is likely to be the same. All results from first run retention time up to third run retention time were within the recommended limit of 6 mg/L set by WHO. Analysis by t-test at 95% confidence level showed that the comparison means of CWF1 and CWF2 on turbidity removal was statistically different with p values less or equal to 0.05 ($p \leq 0.05$). Hence both CWF1 and CWF2 are efficient in turbidity removal. However, CWF2 might be more efficient in removing turbidity than CWF1 due to the presence of activated carbon inside the filter. Activated carbon has been reported to have excellent results in removing turbidity (Yang et al. 2020. Alford et al. 2023). It has also been reported that ceramic water filters from the markets are excellent in turbidity removal as well (Rivera et al. 2020).

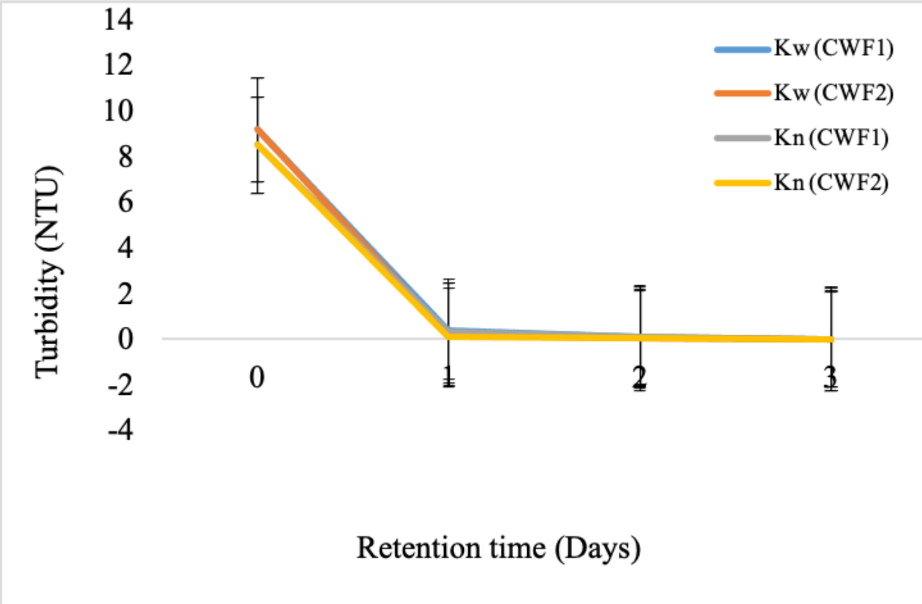

Figure 3: A plot of turbidity as a function of retention time for filtration of water samples through CWF1 and CWF2

Efficiency of Ceramic Water Filters on the Removal of Total Suspended Solids

The ability of common ceramic water filters to remove total suspended solids (TSS) in water from Kwakilosa river and Kalenga pond varied from 16% to 24% (Figure 4). The filtrates from the first run (one-day retention time) and third run (three-days retention time) were likely to be the same in both CWF1 and CWF2. The mean on the reduction of TSS by common ceramic filters was statistically different with p value of 0.02, which is less than 0.05 ($p \leq 0.05$). Based on the findings both CWF1 and CWF2 are not efficient in removing total suspended solids. It is suggested that the filter designs of both CWF1 and CWF2 does not support an effective filtration of total suspended solids.

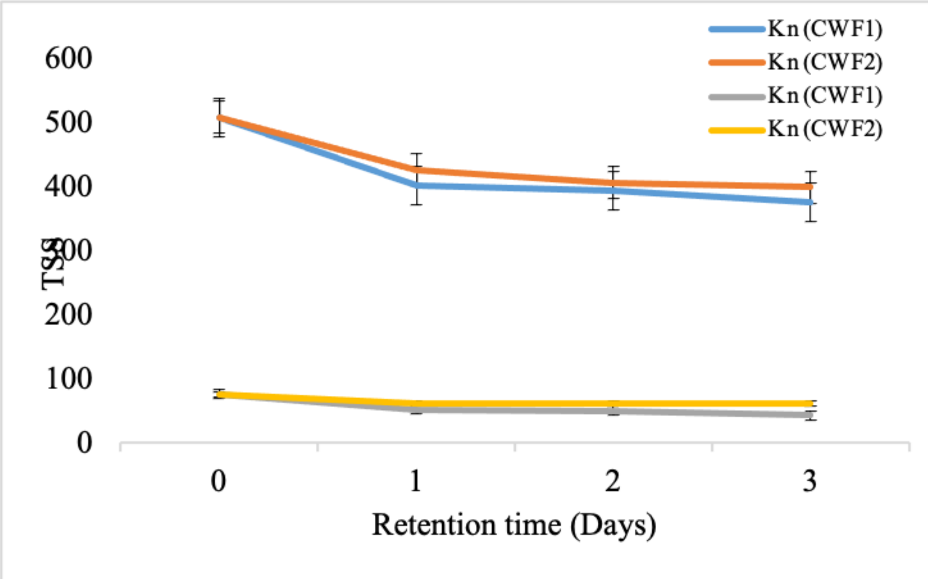

Figure 4: A plot of concentration of total suspended solids as a function of retention time for filtration of water samples through CWF1 and CWF2

Efficiency of Ceramic Water Filters on the Removal of Organic matter

The ability of CWF1 for the reduction of BOD_5 for water from Kwakilosa river was 50% and Kalenga pond was 58% as shown in Figure 5. For CWF2, the ability to reduce the levels of BOD_5 for water from Kwakilosa river and Kalenga pond was 100%. CWF2 maintained the maximum efficiency removal of BOD_5 for about 100% since the first run (one-day retention time). The statistical values at 95% confidence interval for both CWF1 and CWF2 was statically different with p values of 0.00 which is less than 0.05 ($p \leq 0.05$) CWF2 was more efficient in removing organic matter than CWF1. This might be due to the existence of the activated carbon in CWF2 which increased its performance in removing the organic matter. Also, conditions such as dissolved oxygen and temperature can decrease the ability of water filters to remove organic matter (Kiagho et al. 2016). Therefore, low performance of CWF1 might be caused by factors such as dissolved oxygen and temperature.

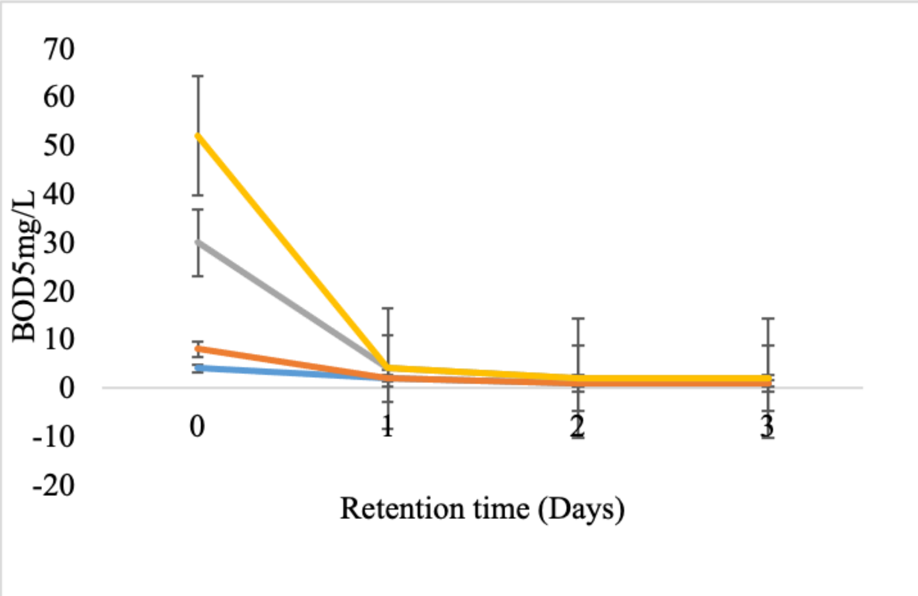

Figure 5: A plot of concentration of BOD_5 as a function of retention time for filtration of water samples through CWF1 and CWF2

Efficiency of Ceramic Water Filters towards Colour Removal

Figure 6 shows the results on the reduction of colour from natural water experiments. In the first run (one-day retention time), the colour removal for CWF1 was 56% and 54% for water from Kwakilosa river and Kalenga pond respectively. While for CWF2, the removal efficiency was 100% for water from both Kwakilosa river and Kalenga pond. The colour remove efficiency for CWF2 was within the WHO and TBS recommended levels of less than 15 PtCo since the first day run (one-day retention time). Statistical analysis of t-test at 95% confidence level showed that the comparison of mean for CWF1 and CWF2 on colour removal was statistically different with p values of 0.04 which is less than 0.05 ($p \leq 0.05$). CWF1 is less efficient in removing colour compared to CWF2. The difference in performance might be due to the presence of activated carbon in CWF2 which increased the ability of the water filter in removing colour.

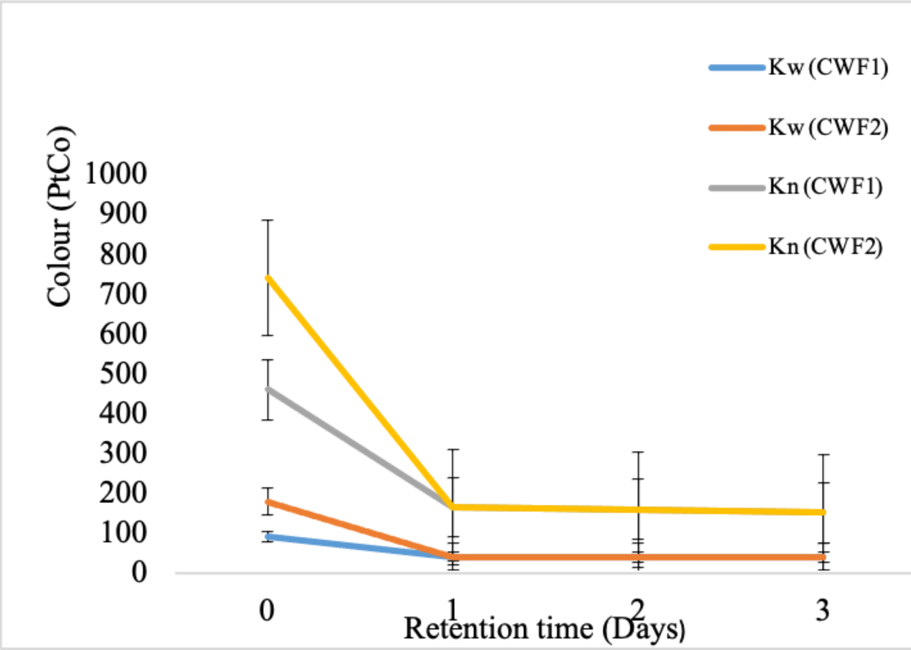

Figure 6: A plot of concentration of colour as a function of retention time for filtration of water samples through CWF1 and CWF2

Efficiency of Ceramic Water Filters towards the Removal of Heavy Metals

Both ceramic water filters are specific towards removing certain heavy metals as shown in Table 2. Water from Kwakilosa river contained no nickel but CWF2 showed greater ability in removing nickel for water from Kalenga pond which contained nickel. The comparison mean of CWF1 and CWF2 on removing heavy metals was statistically different with p of 0.04 which is less than 0.05 ($p \leq 0.05$) using a paired sample t-test at 95% confidence interval. The ability of both CWF1 and CWF2 was depending on the type of heavy metals and type of water filter as well. Heavy metals such as Cr, Cu, Zn and Pb were above the standard guidelines set by both TBS and WHO as indicated by Table 1. CWF1 was able to remove Pb while CWF2 was able to remove Pb and Zn. The ability of both CWF1 in removing other heavy metals such as Cr, Cu, Ni and Mn was generally low. Based on the findings it was noted that there was no ceramic water filter that was able to remove all types of heavy metals from natural water.

Table 2: Efficacy of CWF1 and CWF2 in heavy metals removal for water from Kwakilosa river and Kalenga pond.

Ceramic filter	Retention time (Days)	Cu (%)	Cr (%)	Mn (%)	Ni (%)	Pb (%)	Zn (%)
	1	40	22	21	-	50	84
Kw (CWF1)	2	54	23	24	-	50	85
	3	60	38	35	-	50	86
	1	20	22	19	-	50	84
Kw (CWF2)	2	40	28	25	-	50	88
	3	62	40	32	-	50	92
Kn (CWF1)	1	42	30	66	14	90	76

	2	56	46	68	18	90	83
	3	63	61	75	26	90	84
	1	38	48	61	100	95	83
Kn (CWF2)	2	44	53	64	100	95	85
	3	65	68	69	100	95	90

Conclusions

Both pot type and candle type ceramic water filters were evaluated for their efficiency in removing physical, chemical and biological contaminants from natural water. The obtained results revealed that the ceramic water filtration systems available in the market are effective in removing some water contaminants. There is no ceramic water filter that is able to remove all water contaminants. The laboratory results showed that there was a variation on the performance of water filters in removing contaminants namely *E. coli*, organic matter, TSS, turbidity, colour and heavy metals. CWF2 showed good performance in removing organic matter, *E. coli* and colour. While CWF1 is excellent for Zn removal, CWF2 is excellent for Ni removal. Both CWF1 and CWF2 are excellent for turbidity removal but poor in TSS removal. Based on the laboratory experiment results on the performance of ceramic water filters in removing different contaminants from natural water experiments demonstrated that CWF2 was more capable of providing safe drinkable water. This study revealed that candle type filter is more efficient in removing water contaminants than pot type filter. It is suggested that CWF2 is more effective than CWF1 due to the presence of activated carbon inside the filter which can be able to remove contaminants. This potential observation has not been reported previously. It was further revealed that there was strong association between the retention time and the ability of water filters towards the removal of water contaminants because the filters from the market showed a good performance in removing *E. coli*, turbidity and heavy metals in third day retention time.

Acknowledgement

We acknowledge Mkwawa University College of Education for material support.

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