Performance of Locally Produced Ceramic Pot Filters for Drinking Water Treatment in Rwanda

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Abstract

Global water safety is facing great challenges due to increased population and demand. Ceramic water filters can be a solution at the household level drinking water treatment, now they are made and used in Rwanda. However, no scientific studies have been conducted to find out the performance of ceramic pot filters made in Rwanda. The aim of this study was to determine the performance of ceramic pot filter produced by Rwandan local potters. Water samples were collected from Nyirambaragasa stream. Turbidity, electrical conductivity, dissolved solids, pH, heavy metals, hardness and alkalinity were analyzed before and after filtration with ceramic pot filter. The results showed that after filtration pH, electrical conductivity and dissolved solids were increased. Turbidity and alkalinity were decreased. Sample water showed absence of chromium (Cr) and copper (Cu). Iron, Manganese and Zinc were decreased and they were in the range of WHO guideline for drinking water. Lead (Pb) and Cadmium (Cd) were decreased but they were above WHO guideline. The ceramic pot filter made by Rwandan local potters showed the major potential to be used for drinking water treatment in rural areas mainly for its low operational level and maintenance requirements.

Keywords: *Rwanda, Ceramic pot filter, Drinking water, Water treatment*

I. INTRODUCTION

In developing countries, the access to clean drinking water continues to be an important concern for human health [1]. According to World Health Organization (WHO), 663 million people around the world have no access to improved drinking water sources, and many more lack access to safe water as defined by the WHO risk-based guidelines for drinking-water quality [2]. Most of poorest people in developing countries must collect water outside the home and are responsible for managing (e.g. treating and storing) it themselves at the household level because of the high cost of water distribution and wastewater treatment plant systems [3].

Contaminated water and poor sanitation cause deaths worldwide where every year there are 2 million diarrheal deaths related to unsafe water, sanitation, and hygiene; particularly susceptible are children, the elderly and immuno-compromised individuals, who are most vulnerable to diarrheal and other waterborne infectious diseases the vast majority among children under 5 [4].

Household water treatment (HWT) and safe storage is a new health intervention that enables people to treat water in their homes, and can lead to dramatic improvements in drinking water quality and reductions in diarrhea disease making an immediate difference to the lives of those who rely on water from polluted rivers, lakes and, in some cases, unsafe wells or piped water supplies [5].

Rwanda is a landlocked East African country with a green, mountainous landscape; it is that why it is called “country of thousand hills”. Most of Rwandans live on the hills where essential infrastructure [6] and access to drinking water are costly and challenging, respectively. Most people in rural and urban areas are still drinking untreated water from surface water bodies, which have high turbidity and microbiological contamination. In addition, the containers [7] used to fetch and store drinking water at the household level are not clean enough; this is the other cause of water borne disease for people [8]. Therefore, silver ceramic water filters can be a solution at the household level drinking water treatment.

HWT interventions have the potential to solve the problem where piped water systems are not possible or do not deliver safe water, potentially resulting in substantial positive health impacts in developing countries where it helps in the removal of microbial contamination, dissolved solids, turbidity, and change the pH close to neutrality. Systematic reviews of field trials have suggested that household-based water quality interventions such as appropriate treatment and safe storage are effective in reducing diarrheal disease [9].

Locally produced ceramic pot filters have the advantages of lower cost, use of local materials, labour, and expertise, and possibly greater potential for local investment and entrepreneurship [3]. It has been found that well-characterized filter disks constructed using the Potters for Peace recommended methods reduced Escherichia coli by $97.8% under controlled laboratory conditions, with highest reductions achieved through application of colloidal silver [10].

It has been reported that in Cambodia, a geometric mean 98% reduction in E. Coli of local ceramic filters after 0–4 years in household use and a mean 46% reduction in diarrheal disease among users versus non-users [11]. [9] reports a 3.0–6.8 $\log_{10}$ reduction of E. coli over six influent/effluent paired samples and a 3.3–4.9 $\log_{10}$ reduction of sulfite-reducing Clostridium spores (a protozoan surrogate) over 12 paired influent/effluent samples in a comparative study of Potters for Peace-style filters from Nicaragua, Ghana and Cambodia.

Nowadays, most of the household water treatment methods used in Rwanda are boiling and disinfection by using disinfectant like SÛR EAU. But boiling is known to require high energy and doesn't remove heavy metals and other chemicals. Disinfection using SÛR EAU as disinfectant, is known to remove pathogens but it doesn't have any effect on heavy metals [12].

Currently, in Rwanda, ceramic pot filters are being made by local potters and being used for drinking water treatment in different areas of the country especially in rural areas in order to solve that problem. However, no scientific studies have been conducted to find out the performance of ceramic pot filters made by local potters in Rwanda.

The purpose of this study was to determine the performance of locally produced ceramic pot filters for drinking water treatment made by Rwandan local potters in order to know the quality of filtrated water when those ceramic pot filters are used.

II. MATERIAL AND METHODS

A. Sampling and description

Nyirambaragasa stream (Fig.1) is a stream located in Kacyiru sector, Gasabo District, Kigali City, Rwanda. Wastewaters from Village d' Enfant SOS Kacyiru and wastewaters coming from Gacuriro are discharged in this stream. Water samples were taken randomly from Nyirambaragasa stream in June 2017, collected in a cleaned jerrycans of 20 litres using a cleaned cup then brought in laboratory at College of Science and Technology, University of Rwanda, for analysis. The ceramic pot filter was purchased from Rwandan local potters at Kacyiru sector, Gasabo District, Kigali City, Rwanda.

Fig.1: Nyirambaragasa stream

B. Chemical and reagents

All chemicals and reagents including methyl orange, Eriochrome Black T and ethylenediaminetetraacetic acid (EDTA) solution were purchased from Sigma-Aldrich, Steinheim, Germay unless otherwise stated.

C. Turbidity

Turbidity of water samples was measured using photometric method with a Portable Nephelometer's Turbidity Meter that was calibrated with turbidity standards of 1; 10; 100 and 1000 NTU prior to the analysis.

D. pH test

pH was measured using a pH meter (Benchtop pH meter F20 kit, METTLER TOLEDO, Singapore) that was calibrated using buffer solutions of 4 and 7 pH.

E. Electrical conductivity and total dissolved solids

Electrical conductivity and total dissolved solids were measured using Electric conductometer (Conductivity Meter CD-4307SD, Mother Tool, Singapore).

F. Hardness

Water hardness was determined by a complexometric titration using a standard ethylenediaminetetraacetic acid (EDTA) solution. The EDTA complex was prepared first with the Ca^{2+} and Mg^{2+} respectively. The indicator used in this experiment was Eriochrome Black T. This indicator reacts with Mg^{2+} (colorless) to give a red complex. Standard EDTA solution was added to water sample and the end point was shown by an indicator that was red in the presence of calcium and magnesium ions and blue in their absence.

G. Alkalinity

Alkalinity of water samples was determined by potentiometric titration method (titration of water samples by strong acid (sulphuric acid 98%) in presence of methyl orange indicator).

H. Heavy metal analysis

Heavy metals like chromium, iron, cadmium, manganese and lead were analysed using Atomic Absorption spectroscopy (ZEEnit 650 P (Graphite Furnace), Analytikjena, Singapore).

I. Statistical calculations

Each experiment was repeated thrice and the 'mean ± standard deviation' values were calculated through Microsoft Excel 2016.

III. RESULTS AND DISCUSSION

Tables 1 and 2 are showing the physical parameters and heavy metals measured from the water samples, respectively.

Table 1: Physical parameters measured from raw water samples.

Parameter	Raw water
pH	7.2 ± 0.13
EC (µS/cm)	523.3 ± 1.53
TDS (mg/L)	243.3 ± 2.08
Turbidity (NTU)	33.3 ± 1.15
Alkalinity (mg $CaCO_3$/L)	124.3 ± 2.08

Table 2: Heavy metal measured from raw water samples.

Parameters	Raw water (mg/L)
Lead (Pb)	0.487 ± 0.02
Cadmium (Cd)	0.031 ± 0.01
Chromium (Cr)	0.000 ± 0.00
Iron (Fe)	5.531 ± 0.30
Manganese (Mn)	1.006 ± 0.03
Zinc (Zn)	0.040 ± 0.01
Copper (Cu)	0.000 ± 0.00

Tables 3 and 4 are showing the physical parameters and heavy metals measured from filtrated water, respectively.

Table 3: Physical parameters measured from filtrated water.

Parameter	Filtrated water
pH	7.4 ± 0.41
EC (µS/cm)	578.7 ± 1.53
TDS (mg/L)	288.7 ± 1.53
Turbidity (NTU)	8.9 ± 0.53
Alkalinity (mg $CaCO_3$/L)	63.3 ± 0.76

Table 4: Heavy metals measured from filtrated water.

Parameters	Treated water (mg/L)
Lead (Pb)	0.06 ± 0.010
Cadmium (Cd)	0.01 ± 0.002
Chromium (Cr)	0.00 ± 0.000
Iron (Fe)	1.50 ± 0.300
Manganese (Mn)	0.40 ± 0.020
Zinc (Zn)	0.02 ± 0.010
Copper (Cu)	0.00 ± 0.000

Tables 5 and 6 are showing allowable concentrations of physical parameters and heavy metals in potable water, respectively.

Table 5: Acceptable levels of physical parameters in potable water by WHO.

Parameter	Treated water
pH	6.5 - 8.5
EC (µS/cm)	400
TDS (mg/L)	1000
Turbidity (NTU)	5
Alkalinity (mg $CaCO_3$/L)	20-200

Table 5: Allowable concentrations of heavy metal in potable water by WHO.

Parameters	Treated water (mg/L)
Lead (Pb)	0.010
Cadmium (Cd)	0.003
Chromium (Cr)	0.050
Iron (Fe)	2.000
Manganese (Mn)	0.400
Zinc (Zn)	3.000
Copper (Cu)	2.000

A. pH

pH is an important parameter in evaluating the acid-base balance of water. It is also the indicator of acidic or alkaline condition of water status. WHO has recommended maximum permissible limit of pH from 6.5 to 8.5. The current study indicates that the pH value in raw and filtrated water was 7.2 ± 0.13 and 7.4 ± 0.41 respectively and it is in the range of WHO standards. pH after filtration was increased, which is a result of a reduction of active H^+ ions by ceramic pot filter. This increase in concentration of pH may occur when water reacts with dissolved carbonate ions (CO_3^{2-}) from clay where water has passed over. Basically, the pH is determined by the amount of dissolved carbon dioxide (CO_2), which forms carbonic acid in water [13].

B. Turbidity

The turbidity of water depends on the quantity of solid matter present in the suspended state. It is a measure of light emitting properties of water and the test is used to indicate the quality of waste discharge with respect to colloidal matter. The mean turbidity value in raw water and filtrated water was 33.3 ± 1.15 and 8.9 ± 0.53 NTU, respectively; but it was above the WHO guideline value of 5 NTU. The turbidity of the filtrated water has been decreased due to the remaining of molecules larger than water molecules that were in raw water being retained by pores during filtration [14].

C. Electric conductivity (EC)

Pure water is not a good conductor of electric current rather's a good insulator. Increase in ions concentration enhances the electrical conductivity of water. Generally, the amount of dissolved solids in water determines the electrical conductivity. Electrical conductivity (EC) actually measures the ionic process of a solution that enables it to transmit current. According to WHO standards, EC value should not exceed 400 µS/cm. Current study indicate that the electric conductivity in raw and filtrated water was 523.3 ± 1.53 and 578.7 ± 1.53 µs/cm, respectively; and it is above the limit of WHO standards. These results clearly indicate that raw and filtrated water were considerably ionized and have high level of ionic concentration activity due to dissolve solids. The increase in electric conductivity may due to the presence of some ions leaching from filter material like Ca^{2+}, Al^{3+}, OH^- [15].

D. Total dissolved solids (TDS)

Water is able to dissolve a wide range of inorganic and some organic minerals or salts [16] such as potassium, calcium, sodium, bicarbonates, chlorides, magnesium, sulfates etc. These minerals produced un-wanted taste and diluted color in appearance of water. This is the important parameter for the use of water. The water with high TDS value indicates that water is highly mineralized. Desirable limit for TDS is 500 mg/L and maximum limit is 1000 mg/L which prescribed for drinking purpose. The concentration of total dissolved solid found in raw and filtrated water was 243.3 ± 2.08 and 288.7 ± 1.53 mg/L, respectively; and it is within the limit of WHO standards. High values of TDS in ground water are generally not harmful to human beings, but high concentration of these may affect persons who are suffering from kidney and heart diseases. Water containing high solid may cause laxative or constipation effects. The increase in concentration of total dissolved solid may due to the presence of some compounds leaching from filter material, not only hardness ions, but also such compounds as soluble iron, sulphates, dissolved silica, sodium and others [17].

E. Alkalinity

The concentration of alkalinity has been decreased from 124.3 ± 2.08 mg $CaCO_3$/L in raw water to 63.3 ± 0.76 mg $CaCO_3$/L in treated water. The alkalinity of water is related to pH (hydroxide), the salts of weak acids (mainly bicarbonate and carbonate), borate, silicate, and phosphate in water [18].

F. Heavy metals

Clay mineral indicates that the basic unit cell consists of a stacking of a tetrahedron on top of the octahedral unit. In general, the tetrahedral positions are occupied by silicon ions and two thirds of the octahedral positions are occupied by Aluminium ions [19], [20].

Clay minerals adsorb ions through exchangeable cations and electrostatically bound counter ions in the diffusion layer which is formed because of the surface charge. Cations may be displaced on the surface of clay by cation exchange capacity and easy cation displacement is a function of cation size and charge and the strength of adsorption increase as a function of cation valence and hydrated size ($Al^{+3} > H^+ > Ca^{2+} > Mg^{2+} > K^+ \geq NH^{4+} > Na^+$). As it is shown in Table 2, raw water did not contain metals like Chromium and Copper. The absence of those metals may due to the source of the stream [21], [22].

The concentration of Lead (Pb), Cadmium (Cd), iron (Fe), Manganese (Mn) and Zinc (Zn) in raw water was 0.487 ± 0.02, 0.031 ± 0.01, 5.531 ± 0.30, 1.006 ± 0.03 and 0.040 ± 0.01, respectively. In filtrated water, it was 0.06 ± 0.01, 0.01 ± 0.002, 1.5 ± 0.3, 0.4 ± 0.02 and 0.02 ± 0.01, respectively (Table 4). The treated water showed the concentration of Lead (Pb) and Cadmium (Cd) to be higher than WHO standard guideline but others like iron (Fe), Manganese (Mn) and Zinc (Zn), their concentration was decreased to be under WHO standard guideline.

IV. CONCLUSION

In this study, the performance of ceramic pot filter produced by Rwandan local potters was evaluated. The results found agrees with historical data showing that ceramic pot filter is capable to reduce heavy metals and turbidity, increase pH and conductivity which suggests that the filter increase the concentration of total dissolved solids. Based on the results, it is concluded that the ceramic pot filter is an effective and appropriate technology that improves both water quality and human health in rural communities. An educational component that includes safe storage, aseptic cleaning procedures, and follow-up visits to ensure continued usage and replacement of broken pieces is necessary. Further study on the removal rates of bacteria and viruses is recommended.

REFERENCES

[1] T. D. Gardner and J. D. Guggenberger, "Use of ceramic pot filter (CPF) technology under pressure in an in-line pumping system," Water Science and Technology: Water Supply, Vol. 18, No. 3, pp. 843-852, Jun. 2018.

[2] WHO. (2016). Drinking-water Fact Sheet. World Health Organization. [Online]. Available: http://who.int/ mediacentre/factsheets/fs391/en/

[3] D. Van Halem, H. Van Der Laan, A. I. A. Soppe and S. G. J. Heijman, "High flow ceramic pot filters," Water research, Vol. 124, pp. 398-406, Nov. 2017.

[4] L. M. Casanova, A. Walters, A. Nagahawatte, and M. D. Sobsey, "Ceramic pot filter user satisfaction and water quantity production in tsunami-affected Sri Lankan communities," Journal of Water Sanitation and Hygiene for Development, Vol. 3, No.4, pp. 646-648, Dec. 2013.

[5] P. Martínez-Santos, "Determinants for water consumption from improved sources in rural villages of southern Mali," Applied Geography, Vol. 85, pp. 113-125, Aug. 2017.

[6] N. J. Claude and N. Pascaline, "A Study on Interdependent and Asymmetrical Behaviours Associated with Land use and Land Cover at Ruhande, Huye, Rwanda," International journal of innovative research & development, Vol.4, No. 2, pp. 217-222, Feb. 2015.

[7] J.C. Claude and N. Pascaline, "Concepts of Umutara and Imigongo colour based design in the traditional arts of Rwandans and their applications in interior and fashion technologies," International journal of innovative research & development, Vol. 4, No. 9, pp. 334-344, Aug. 2015.

[8] C. B. Sekomo, E. Nkuranga, D. P. Rousseau andP. N. Lens, "Fate of heavy metals in an urban natural wetland: the Nyabugogo Swamp (Rwanda)," Water, Air, & Soil Pollution, Vol. 214, No. 1-4, pp. 321-333, Jan. 2011.

[9] H. Van der Laan, D. Van Halem, P. W. M. H. Smeets, A. I. A. Soppe, J. Kroesbergen, G. Wubbels and S. G. J. Heijman, "Bacteria and virus removal effectiveness of ceramic pot filters with different silver applications in a long-term experiment," Water research, Vol. 51, pp. 47-54, Mar. 2014.

[10] V. A. Oyanedel-Craver and J. A. Smith, "Sustainable colloidal-silver-impregnated ceramic filter for point-of-use water treatment," Environmental science & technology, Vol. 42, No. 3, pp. 927-933, Dec. 2007.
[11] J. Brown, S. Proum and M. D. Sobsey, "Sustained use of a household-scale water filtration device in rural Cambodia," Journal of water and health, Vol. 7, No. 3, pp. 404-412, Sep. 2009.
[12] J. Brown, and M. D. Sobsey, "Microbiological effectiveness of locally produced ceramic filters for drinking water treatment in Cambodia," Journal of water and health, Vol. 8, No. 1, pp. 1-10, Mar. 2010.
[13] J. Rayner, X. Luo, J. Schubert, P. Lennon, K. Jellison and D. Lantagne, "The effects of input materials on ceramic water filter efficacy for household drinking water treatment," Water Science and Technology: Water Supply, Vol. 17, No. 3, pp. 859-869, May. 2017.
[14] C. Salvinelli, A. C. Elmore, M. R. Reidmeyer, K. D. Drake and K. I. Ahmad, "Characterization of the relationship between ceramic pot filter water production and turbidity in source water," Water research, Vol. 104, pp. 28-33, Nov. 2016.
[15] Y. He, G. Huang, C. An, J. Huang, P. Zhang, X. Chen and X. Xin, "Reduction of Escherichia Coli using ceramic disk filter decorated by nano-TiO2: A low-cost solution for household water purification," Science of The Total Environment, Vol. 616, pp. 1628-1637, Mar. 2018.
[16] N. Pascaline, M. Theophile, N. J. de Dieu, M. J. Pauline, N. J. Claude, U. Placide, "A study on sediments depositional mechanism at Nayakankuppam coast, Tamilnadu, India," International Journal of Engineering Research and General Science, Vol. 3, No. 6, pp. 478-492, Nov-Dec. 2015.
[17] J. Huang, G. Huang, C. An, Y. He, Y. Yao, P. Zhang and J. Shen, "Performance of ceramic disk filter coated with nano ZnO for removing Escherichia coli from water in small rural and remote communities of developing regions," Environmental Pollution, Vol. 238, pp. 52-62, Jul. 2018.
[18] C. Salvinelli, A. C. Elmore, B. R. García Hernandez and K. D. Drake, "Ceramic pot filters lifetime study in coastal Guatemala," Journal of water and health, Vol. 15, No. 1, pp. 145-154, Feb. 2017.
[19] M. M. Kumar, and V. S. Tamilarasan, "Experimental study on expansive soil with marble powder," International Journal of Engineering Trends and Technology (IJETT), Vol. 22, No. 11, pp. 504-507, Apr. 2015.
[20] T. Klug, R. Cronk, K. F. Shields and J. A Bartram, "categorization of water system breakdowns: Evidence from Liberia, Nigeria, Tanzania, and Uganda," Science of the Total Environment, Vol. 619, pp. 1126-1132, Apr. 2018.
[21] A. D. Raval, I. N. Patel, and J. Pitroda, "Ceramic waste: Effective replacement of cement for establishing sustainable concrete," International Journal of Engineering Trends and Technology (IJETT), Vol. 4, No. 6, pp. 2324-2329, 2013.
[22] A. Pérez-Vidal, J. Diaz-Gómez, J. Castellanos-Rozo, and O. L. Usaquen-Perilla, "Long-term evaluation of the performance of four point-of-use water filters," Water research, Vol. 98, pp. 176-182, Jul. 2016.