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Earthenware Sand Water Filter for Drinking Water Treatment

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Abstract

The need for effective household water treatment and safe storage among low-income vulnerable populations cannot be overemphasized. This study assessed the efficacy of earthenware sand water filter in the treatment of groundwater from low-income community in Ibadan metropolis. A two-unit filter consisting of a sand filter and storage pot were constructed for the assessment over a two-week period. Results showed about 83% reduction of *Escherichia coli* which is equivalent to 0.78 log reduction value. Hence the filter did not meet the performance target of $\geq$ 2 and $\geq$ 4 for protective or highly protective systems. The estimated cost per filter (N4,386.52) is comparatively low and may be lower with bulk production. The sand filter has good prospect for household use if operated for longer period to enable the biolayer to mature. Further research is recommended to determine the optimum conditions for performance, evaluate removal of bacteria, protozoa, and viruses and determine community viability and sustainability.

Filtre À Sable Du Poteries En Terre Cuite Pour Le Traitement De L'eau Potable

Abstrait

La nécessité d'un traitement efficace de l'eau domestique et de la sécurité des populations vulnérables à ne peut pas être surestimée. Cette étude examine l'efficacité de Filtre à sable du sol d'une communauté rurale à centre-ville à Ibadan. Un Filtre a deux unités qui consiste, d'un filtre à sable du sol sont construits pour le but d'entamer la recherche qui durera deux semaines. Les résultats montrent qu'il y avait une réduction de 83% de Escherichia coli qui est équivalent de 0,78 réduction de valeur du bois. Par conséquent, le filtre n'a pas atteint l'objectif de performance de ≥2et≥ 4 pour les systèmes de protection ou hautement protectifs. Le coût estimé du filtre (4386,52 N) est comparativement faible et peut reduire à la production en masse. Le filtre à sable du sol a de bonnes perspectives pour une utilisation domestique s'il est utilisé pendant une longue période. Des recherches supplémentaires sont recommandées pour déterminer les conditions optimales de performance, évaluer l'élimination des bactéries, des protozoaires et des virus et déterminer la viabilité et la durabilité de la communauté.

Introduction

Clean and accessible water was described by the Government of Canada (2017) as being "critical to human health, a healthy environment, poverty reduction, a sustainable economy, and peace and security". However, more than 40% of the global population lack access to clean water. Many countries in the developing world rely on water from polluted sources for drinking and other domestic uses, hence the occurrence of water and sanitation-related diseases which constitute about 80% of the burden of diseases.

In Nigeria, 66% of households have access to an improved source of drinking water, 74% in urban areas and 58% in rural area (NPC & ICF, 2019). Improved sources of drinking water used in Nigeria include tube wells or boreholes (41% in urban and 34% in rural households), protected dug wells or springs (13% in urban and 12% in rural households), and public taps/standpipes (7% in urban and 8% in rural households). However, 26% of urban households and 42% of rural households still depend on unimproved sources for their drinking water. The most common unimproved sources of drinking water in rural households of Nigeria are unprotected dug wells (22%) and surface water (15%) (NPC & ICF, 2019b).

In order to address the problem of inadequate water supply, the UN General Assembly adopted 17 Sustainable Development Goals (SDGs) in July 2017, of which SDG 6, target 6.1 aim to "achieve universal and equitable access to safe and affordable drinking water for all". The target is tracked with the indicator of "safely managed drinking water services". This implies availability of drinking water from an improved water source that is free from faecal pathogens and priority chemical contamination at all time; that is adequate in quantity (available when needed), located on premises (accessible) and is at an affordable price for all (WHO, 2020; United Nations Water, 2016; WHO, 2017).

WHO also reported that 5.3 billion (70.5%) people out of a global number of 7.5 million used safely managed drinking water services. Despite this high percentage, a large disparity exists in access by people living in urban/rural and "low-income, informal, or illegal settlements as this group of people usually have less access to improved sources of drinking water than other residents" (WHO, 2020).

According to WHO/UNICEF (2019), the proportion of Nigerians using safely managed drinking water services in 2017 was only 20%. Also, 90% and 93.5% of urban and rural households respectively did not treat their drinking water; while only 7.0 and 2.5% in urban and rural households respectively use an appropriate treatment method (e.g. boiling, bleaching, filtering, and solar disinfection) (NPC & ICF, 2019b). The implication of this is that a large proportion of the people rely on polluted water sources for drinking and other domestic purposes thus resulting in high burden of water-borne diseases of which is diarrhea.

Study by Oloruntoba *et al.,* (2016) showed that underground water such as wells, boreholes and springs were the most used sources of drinking water in Ibadan, Nigeria. Common containers for storing drinking water in the households include plastic containers, plastic drums, jerry cans, clay pots and basins (Oloruntoba *et al*., 2016). Many studies have documented the possibility of deterioration of microbial quality of drinking water from source to point of use in the household. Folarin *et al*., (2013) reported presence of *Escherichia coli* in some of the households' stored water samples, even though the source water was free of contamination. This was associated with the methods of handling along the supply chain and storage in the household. It therefore highlights the importance of household water treatment and safe storage.

In the developed countries, public and municipal water systems are regulated; hence a home water treatment system is seldom needed for health protection. The situation in the developing countries is quite different. In Nigeria for instance, water treatment plants are located mostly in state capitals and big towns. Even then, more than fifty percent of the population is not served. Invariably, each household must decide on what type of source to use and the type(s) of water treatment options to be put in place for a specific water quality problem.

Water treatment and conditioning are methods used to improve water quality by reducing harmful contaminants in the water. Several point-of-use water treatment technologies have been developed, tested and used in communities without access to safe drinking water in developing countries (Sobsey *et al*., 2008). Some of these are: simple storage (sedimentation), coagulation with alum followed by sedimentation, filtration (straining with a piece of cloth, monofilament filter, using ceramic candle filter, biosand filter), disinfection (boiling, chlorination, ultra violet light and SODIS).

The Centre for affordable water and sanitation technology, CAWST, (2012) described a biosand filter (BSF) as an adaptation of the traditional slow sand filter. The filter is smaller and adapted for intermittent use, making it suitable for households. It is a multi-barrier approach that is designed to reduce the risk of drinking unsafe water. Out of the five steps of the multi-barrier approach to safe drinking water (protection of source water, sedimentation, filtration, disinfection, and safe storage), biosand filters use sedimentation, filtration, and disinfection methods in improving water quality (CAWST, 2012). The filter is normally made of concrete or plastic. It is filled with layers of sand and gravel. As water passes through the filter, a biolayer builds up on top of the sand and helps to remove the pathogens. The effectiveness of the filter is based on the development of a biolayer within 2 weeks to 30 days depending on the quality of water and the mode of operation in line with standard procedures (CAWST, 2012). In many rural and urban slum settlements in Nigeria, earthenware pots made of clay are commonly used for storing drinking water because they traditionally keep the water cool. The use of the earthenware pots for construction of sand water filters for use in improving household drinking water quality has not been extensively explored in the country. However, WHO has reiterated that household water treatment interventions may play a substantial role in protecting health in communities that do not have access to treated/piped water supply. This study was therefore designed to assess the efficacy of a low-cost household earthenware sand water filter constructed with earthenware pot under laboratory conditions and its cost implication.

Materials and Methods

This study is part of a larger one that sought to find a lasting solution to the problem of inadequate supply of potable drinking water in low-income households. The scope of this paper therefore covers the design, construction, and assessment of efficacy of earthenware sand water filter in improving bacteriological quality of drinking water in the households.

Construction of earthenware sand water filter for household drinking water treatment

The study was exploratory and laboratory based. Earthenware pots made from clay soil were purchased from a local market. Beach sand and gravel was washed thoroughly, dried and subjected to grain size distribution with an electric shaker-timer.

Holes for outlet pipes and taps were drilled into the earthenware pots and the filter construction was adapted from Kamfut (1994), Skinner and Shaw (1999) and CAWST (2012). About two-third of the pot was filled with media which consisted of gravel (4 mm diameter grain and depth of 10cm), coarse sand (1 to 2 mm diameter and depth of 10 cm) and fine sand 0.2 to 0.5mm diameter and depth of 20cm). The two pots were connected with a short pipe and hose (with clip). Covers made of wood were also constructed for the pots. The media grain sizes are shown in Figures 1 and 2, Figure 3 shows the cross-section of the filter, while Figure 4 shows the sand water filter and the treated water storage pot.

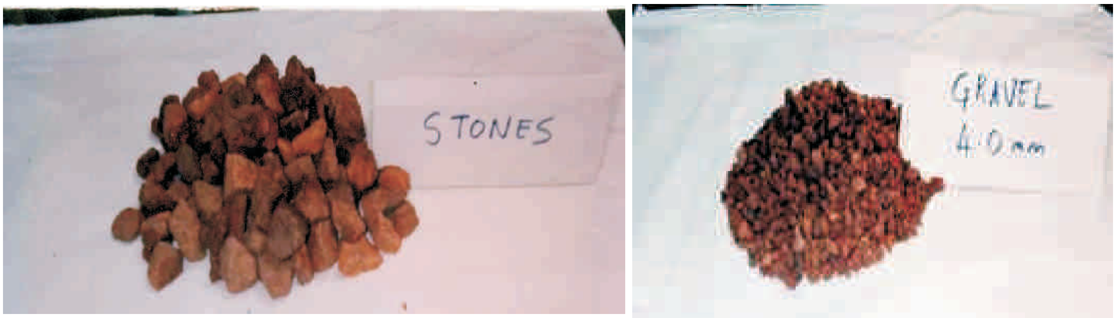

Figure 1: Size of stone and gravel used for constructing the sand water filter

Figure 2: Size of fine and coarse sand used for constructing the sand water filter

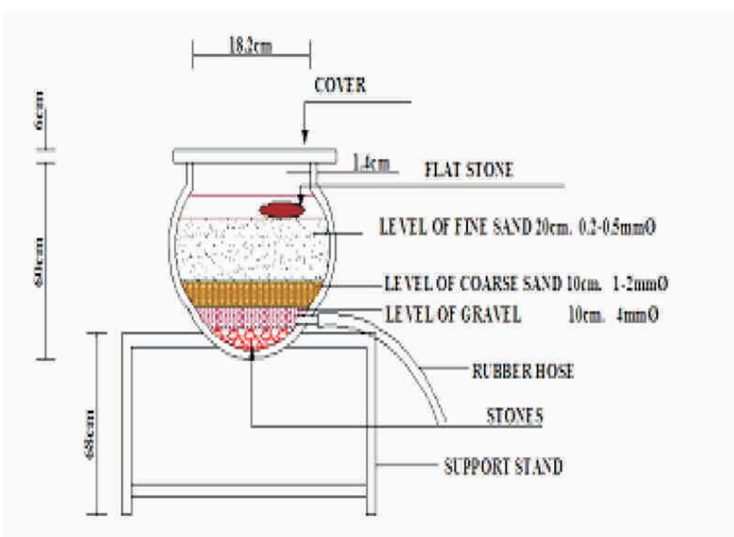

Figure 3: Cross sectional view of earthenware sand water filter

Figure 4: Earthenware sand water filter (Twin pot, downward flow)

Filter Operation

Water collected from a community well at Kube community, an urban slum in Ibadan North Local Government Area was allowed to sediment for 12 hours. Operation of the filter started by adding a bucket of settled water (about 15 litres) to the filter. More water was added to achieve a head of water of about 5 cm. On the first day, about 130 litres of settled water was filtered in 2.18 hours (2 hours, 11 minutes) to give a flow rate of about one (0.99) litre per minute. In line with standard operating procedures for biofilter, water from a single source was used, and the filter was not allowed to drain completely before filling.

The biolayer started developing after water had passed through the filter many times without allowing the surface layer to dry; and it became effective after one week. At this point, 20 litres of water filtered in 45 minutes produced more than enough drinking water (based on WHO's recommendation of 2 litres per person per day) for a family of five.

Water analysis

Sampling bottles were sterilized using standard methods recommended by APHA (1998) and kept tightly closed after removing them from the oven. Samples were collected under aseptic condition from the well (before and after sedimentation), and once a week from the earthenware sand water filter. Bacteriological quality (Total coliform and *Escherichia coli*) of water samples was assessed using standard methods by APHA (1998). Results of analysis were compared with WHO guidelines for drinking water quality.

Treatment Performance Using Risk Assessment Model

The WHO recommended microbiological performance criteria for HWT technology classification was adopted. The efficacy of water treatment with the earthenware sand water filter was assessed based on reduction in microbe level to ensure water safety.

The percentage removal of microbes during treatment is calculated with equation 1. In this study, bacteria, and specifically, *Escherichia coli* was used as the target pathogen because of its prevalence in human and animal faeces as compared with other thermotolerant coliforms, and its use as an indicator of faecal contamination in drinking water (WHO, 2011a; Odonkoror and Ampofo, 2013). In addition, two pathogens, rotavirus and *Escherichia coli*, are responsible for most cases of moderate-to-severe diarrhea in low-income countries. Other important pathogens include Cryptosporidium and Shigella (WHO, 2019).

$$\text{Percentage removal of microbes during treatment} = \frac{A - B}{A} \qquad \text{(Equation 1)}$$

Where A = concentration of microbes in raw water
B = concentration of microbes in treated water

The microbiological performance of household earthenware sand water filter technology is presented as a comparison of the concentration of pathogens in water before and after treatment, on a logarithmic basis. The performance target is expressed in terms of log10 reduction in *E. coli* concentration as shown in equation 2 (WHO, 2011b). The performance target is represented by Log reduction values (LRV).

$$LRV = log_{10}(\frac{Pre-treatment}{Post-treatment}) \quad \text{(Equation 2)}$$

Based on the LRV values, the performance can be classified into four as seen in Table 1. A 1-log reduction stands for a ten-fold or 90% reduction in the concentration of pathogens in water.

Cost Analysis of Earthenware Sand Water Filter Production

It was assumed that the earthenware sand water filter is spherical in shape. Therefore, estimation of the volume was based on Archimedes' hat-box theorem which states that "for any sphere section, its lateral surface will equal that of the cylinder with the same height as the section and the same radius of the sphere" (Brilliant, 2020). Costs of bulk production of earthenware sand water filter filters was based on the estimate of the cost of sand, gravel, other materials, and labour.

Results

Bacteriological quality of water from treatment units

Table 2 shows the bacteriological quality of the samples: well water sample from source, settled and treated water. All results are above the WHO guideline values for Total coliform (TC) and *Escherichia coli* (*E. coli*) count per 100ml.

Table 1: Recommended microbiological performance criteria for HWT technology performance classification

Performance classification	Bacteria (log 10 reduction required)	Virus (log 10 reduction required)	Protozoa (log 10 reduction required)	Interpretation
★★★	≥ 4	≥ 5	≥ 4	Comprehensive protection Highly protective (very high pathogen removal)
★★	≥ 2	≥ 3	≥ 2	Comprehensive protection Protective (high pathogen removal)
★	Meets at least 2-star criteria for two classes of pathogens			Interim/targeted protection
-	Fails to meet WHO performance criteria			Little or no protection

Source: WHO, 2011b; & 2016

Table 2: Bacteriological quality of raw, settled, and filtered water samples

Treatment	Raw water (well)	Settled water	Filtration (sand water filter)		WHO
Parameters	x 10^3	x 10^3	Week 1 x 10^3	Week 2 x 10^3	guideline
Total coliform/100ml	2.40	1.8	0.9	0.45	10/100ml
Escherichia coli/100 ml	1.2	0.80	0.35	0.20	0

Table 3: Percentage reduction in TC and across the treatment system

Treatment	TC count x 10^3	% reduction	*E. coli* counts x 10^3	% reduction
Raw water	2.40	-	1.2	-
Settled water	1.8	25%	0.80	33.3%
Filtered (week 1)	0.9	50%	0.35	56.3%
Filtered (week 1)	0.45	50	0.20	42.9%
Total reduction	-	81.25%	-	83.3%

Table 4: Performance of the biosand filter

Treatment	*E. coli* counts x 10^3	% reduction	LRV
Raw water	1.2		
Settled water	0.80	33.3%	0.18
Filtered (week 1)	0.35	56.3%	0.40
Filtered (week 1)	0.20	42.9%	0.24
Total reduction		83.3%	0.78

Evaluation of the Efficacy of the Earthenware Sand Water Filter

There was a substantial reduction in TC and *E. coli* count per 100ml through the treatment system from raw water through filtration (Table 3). After filtration during the second week, 81.3% and 83.3% of TC and *E. coli* respectively were removed.

The treatment performance of the earthenware sand water filter was calculated with equation 2 and results are shown in Table 4. The log removal value (LRV) equivalent to 83.3% of *E. coli* is 0.78. According to the classification by WHO (WHO 2011b; and WHO 2016) the LRV falls in the last category.

Cost Analysis of an Earthenware Sand Water Filter Unit

Assumptions for the calculation of unit price of filter with sectoral representation in Figure 5.

- The clay pot used for constructing the filter is spherical in shape.
- Volume occupied by the different grain size of the media constitute a sector.

According to Brilliant (2020),

Surface area of a sphere = $4\pi R^3$ (Equation 3)

Volume of a sphere = $4/3\pi R^3$ (Equation 4)

If the spherical shape is divided into sectors with radius r, then, area of sector = $2\pi rh$ (Equation 5)

while, volume = $2/3\pi r^2 h$ (Equation 6)

where r = radius

h = height of medium

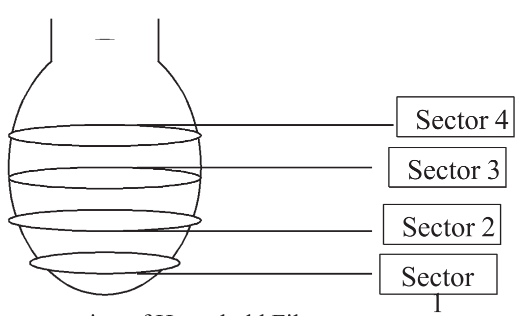

Figure 5: Sectoral Representation of Household Filter

Therefore, from measurements and heights of different grain size in the filter,

Sector 1, r1 – 0.08m, h1 = 0.05m
Sector 2, r2 – 0.28m, h2 = 0.10m
Sector 3, r3 – 0.31m, h3 = 0.10m
Sector 4, r4 – 0.34m, h4 = 0.20m

For sector 1, only one radius is involved, while the three other sectors have two radii each as boundaries for the grain size of the media. Therefore, volume occupied by gravel in sector 2 = (Area1 + Area2/2) x height, h2.

Therefore, the volume occupied by media in the sand filter = V1+ V 2 + V 3 + V4 m3

Total volume V = 0.007 + 0.011 + 0.019 + 0.062 m3

V = 0.093 m3The volume of a tipper load of river (or pit) sand or local gravel = 5 tons = 3.8 m^3

Total volume occupied by coarse and fine sand = 0.019 + 0.062 m^3

= 0.081 m^3

Therefore, No. of filters from a tipper load of sand = 3.8 m^3/0.081 m^3
= 46.91
≈47 filters

Allowing for wastage, it could be approximated to 45 filters
From market survey, price of tipper load of sand was ₦7,000
∴ Cost of sand for one (1) filter = ₦ 155.56

Total volume occupied by stones and gravel = 0.0007 + 0.011 m^3
= 0.0117 m^3

∴ No. of filters from a tipper load of gravel = 3.8 m^3/0.0117 m^3
= 324.79
≈ 325 filters

Allowing for wastage, it could be approximated to 323 filters
From market survey, price of tipper load of local gravel was ₦10, 000
∴ Cost of gravel for one (1) filter = ₦30.96
∴ Cost of sand and gravel for one filter = ₦ 155.56 + 30.96 = ₦ 186.52

Calculation of unit cost of filter

	₦	**K**
1, Cost of sand and gravel	186	52
2. Cost of pots @ ₦350 each	700	00
3. Cost of stands @ N1000 each	2000	00
4. Other materials	1000	00
5. Labour	500	00
Total cost	**4,386**	**52**

If \$1 = 387.46

$\therefore$ **Cost of one filter = ₦4, 386. 52 = US\$11.32**

The above calculation is based on the principle of bulk purchase.

Discussion

Lack of adequate safely managed drinking water is a serious public health in Nigeria and many developing countries. The use of well water in this study was due to the premise that a large percentage of the populace in Nigeria use groundwater sources (especially well water) as the major source of drinking water. This assertion is corroborated by Oloruntoba and Sridhar (2007), Gbadegesin and Olorunfemi (2011) and Egbinola and Amanambu (2014). The study by Egbinola and Amanambu (2014) also affirmed that many (65%) private well owners and users in Ibadan were not aware of contamination problems. Oloruntoba and Sridhar (2007) also reported deterioration of the quality during storage at the household level.

A lot of cultural value is attached to the use of earthenware/clay pots for household drinking water storage by low-income rural and urban slum residents in Nigeria. CDC (2012a) also affirmed that clay pots are the preferred storage container in many cultures because they make water cool during storage. Various studies have attested to the use of these local pots. Study by Gbadegesin and Olorunfemi (2011) reported that 45% of respondents in Ibadan rural areas used local pots for storing drinking water as against 29.3%. In like manner, study by Mohanan *et al* (2017) assessed the effect of different types of storage vessels for 30 days on water quality and concluded that the quality of water stored in clay pot, brass and copper was better than others. The use of earthenware pot for household drinking water therefore holds good promise.

According to CDC (2015), household water treatment at point of collection or use improves water quality and reduces diarrhea diseases in developing countries. Chlorination, flocculants/disinfectant powder, solar disinfection, ceramic filtration, and slow sand filter were the five technologies reported by CDC Safe water System to have been proven and widely implemented in developing countries. Selection of slow sand filtration with pot commonly used by low-income rural and urban slum residents was therefore based on this assertion.

Results for this study showed that the levels of Total coliform and *Escherichia coli* in raw water were far above WHO guideline for drinking water, hence the need for treatment. After settling, about 25% and 33 % reduction in TC and *E. coli* was observed, respectively. By the second week of treatment, 81.3% and 83.3% of TC and *E. coli* had been removed. This is lower than 90- 99% bacterial removal expected when the biolayer on top of the sand filter is fully matured (CDC, 2012b). The slightly low percentage removal may be associated the fact that the biolayer on top ofthe sand was not fully matured as it requires at least around 2-3 weeks (Ranjan and Prem, 2018). However, the result compares favourably with that of Kamfut (1994) who obtained 70 to 80 percent reduction in total coliform. Also, Chukwurah (2003) obtained 99.7 percent reduction in coliform count by using candlestick filters made from a mixture of diatomic powder, sand, and saw dust in a ratio 2:1:1. Application of the performance classification by WHO (2011b; 2016) to the results of this study shows that within the limit of experimental period (2 weeks), the sand filter can be classified as having "little or no protection: because the LRV of 0.78 is below the stipulated ≥ 2 and ≥ 4 for protective or highly protective systems respectively. Wendt *et al* (2015) investigated two point-of-use drinking water treatment systems designed using a carbon filter and foam material as a possible alternative to traditional biosand systems and achieved 4 log10 reduction in viruses, 6 log10 for protozoa, and 8 log10 for bacteria. The outcome of the study is therefore encouraging, and the earthenware sand filter has shown good promise for household use provided the duration of the experiment is extended beyond three weeks. For optimum performance of the filter, Kamfut (1994) observed that the limited bed thickness in small filter units could be complemented with addition of charcoal, marble or limestone depending on desired result.

The cost of a sand filter based on bulk purchase came down to N4,386.52 which is approximately US$11.32. This cost is lower than that reported by CDC (2012b), for which the "average cost for construction of a slow sand filter ranged between US$15 and $60 depending on whether local or imported materials are used". The cost of producing the earthenware sand filter may even be lower with subsidy from government and Non-Governmental Organizations.

Conclusion

The use of earthenware pots for water storage is a common phenomenon in rural and peri-urban communities of Nigeria. The outcome of this study has shown that the earthenware sand filter consisting of sand and gravel media is capable of treating household drinking water to acceptable standard by WHO. Bulk production will also make the price low and affordable for households in low-income communities and settlements. It is therefore important that the filter should be upgraded to protect the health of the users. Filter should be operated for longer period to enhance performance. Further research is recommended to determine the optimum conditions for performance, evaluate removal of bacteria, protozoa, and viruses and determine community viability and sustainability.

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