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Performance evaluation of locally produced ceramic filters for household water treatment in Nigeria

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ABSTRACT

This study investigates the production of ceramic water filters from various clay materials and their performances to improve the physical and bacteriological quality of drinking water. Ceramic water filters were prepared by combining clay with sawdust at various ratios. The water absorption rate, flow rate and microbial removal efficiency were analyzed. The results indicated that some clays produced from Ire Ekiti Brown clay at ratio 50:50 and 40:60, Ire Ekiti Red clay at ratio 40:60 and 30:70 and Isan Ekiti Brown clay at ratio 40:60 and 30:70 all have high absorption rates which resulted from the high sawdust content in the mixture; as sawdust possesses high porosity. Also, filters produced ranging from 60:40 to 40:60, 50:50 to 40:60 and 70:30 to 40:60 for Ire Ekiti brown clay sample, Ire Ekiti red clay sample and Igbara Odo Ekiti clay sample respectively and for both Ikere Ekiti white clay and Ara Ekiti clay samples at 40:60 all showed better microbial removal efficiency as they could remove more than 95% of coliform bacteria and *Escherichia coli*. The Ire Ekiti Brown ceramics filter was considered suitable for producing filter materials based on a recipe combination which varies from 60:40 - 40:60. Ire Ekiti Red and Igbara Odo Ekiti Brown ceramics pot filters both recorded a high flow rate owing to the high porosity of their filter components which is as a result of the higher percentage of the constituents of burn-out material. Of all the ceramic filter produced, 50% to 50% ratio of Igbara odo clay to sawdust gave the best and optimum mix which was found to be highly efficient in the removal of microbes in the water sampled. This research reveals the ability of the ceramic filters made principally from locally available materials (clay and sawdust) for microbial removal in wastewater biotreatment.

Introduction

Universally, water is one of the extremely invaluable and vulnerable natural resources upon which health wholly relies. Therefore, there is an urgent need to both protect and improve water for health [1,2]. Water quality is an increasing

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concern all over the world especially the developing nations [3,4]. The sources of drinking water are under growing threat from pollution, with far-reaching aftereffects on the health of children and for the socio-economic growth of communities and nations [5,6]. In recent years, water pollution has turned out to be a severe problem in most countries of the world especially the developing countries, which primarily occurs due to the indiscriminate disposal of untreated effluents and other chemical and agricultural waste [7–11]. Largely in most of these areas, the people are compelled to drink polluted water because they have no other alternative [12] and almost all water-related diseases are a result of inadequate supply of sufficient clean water for the public [13]. It is suggested that more than 780 million people do not have access to proper and improved drinking water sources [14,15]. There are lot of surface water such as rivers, lakes, non-protected springs and ponds in developing and least developed or under developed countries but the majority of polluted surface waters are attributable to the use by societies living near the water sources for animal watering, laundry, bathing and other domestic uses. Water pollution can simply be explained to be the unsuitability of water for human consumption. Water pollutant usually contain a wide range of pathogens, various biological wastes, different chemical substances, and so on [8].

An instant priority in areas where normal water supplies are compromised as a result of natural disasters, complex emergencies, or outbreaks is a potable drinking water [16]. Populations in affected areas have often been encouraged to preserve their drinking water via boiling and disinfection to secure its microbiological integrity [17], but some individual researchers, private and governmental organizations, non-governmental organizations have extensively researched to provide a point-of-use scheme in water treatment. In his report on household water treatment and safe storage (HWTSS) alternatives in developing countries, Lantagne et al. [18] discussed on the five of the most frequent HWTSS options which include chlorination, filtration (i.e. a blend of biosand and ceramic), combined filtration/chlorination, solar disinfection and combined flocculation/chlorination. For filtration which consists of biosands and ceramics, he asserted that for hundreds of years, porous stones and other various native materials have been applied to filter contaminants than can be seen physically from water and that these filters have been an appealing choice for household treatment as there are a lot of locally available and cheap options for water filtration.

Ceramic water filtration as explained by Agbo et al. [19] is an activity of making water to pass via a permeable ceramic material which is affordable in term of cost and also greatly reduces water-borne disease. Ceramic pot water filters over the years have been the most effective and efficient among several household water treatment technologies [18,20]. Lantagne [21] investigated the most extensively distributed ceramic filters produced by the Potters for Peace (PFP) filter. The ceramic filter has the shape of a flowerpot and it holds 8.2 l of water, it is impregnated with colloidal silver and sits inside a 20–30 l plastic or ceramic receptacle with a spigot. Even though most of the bacteria are eliminated through the filter's small (0.6–3.0 µm) pores in the laboratory test carried out mechanically with the filter, colloidal silver is essential to disable 100 percent of the bacteria. Other merits of ceramic filters locally produced are portability, light weight, affordability and low maintenance requirement. Ceramic filters do not substantially alter temperature and water taste neither do they decrease turbid nature of water unlike chemical or thermal disinfection [22,23]. They potentially have a long useful life of five years or more with proper care and maintenance, even though, manufacturers usually recommend that the filter element should be replaced every 1–2 years [24]. Oyanedel - Craver and Smith [25] discovered that for poor communities, silver coated ceramic pot water filters, constructed using local materials with labour primarily, represent a sustainable point-of-use water treatment technology. Residence of these poor communities (both in developing and least developed countries will immensely benefit from this technology by improving their health through the intake of potable water and also improving their economic through job creation (as the materials used can be sourced for locally within most vicinities of these countries). Ceramic filters have flexibility of design and can be moulded into various shape types like that of flower vases or pots, discs, and candles [26].

The concept of ceramic filtration method for the treatment of drinking water has existed for a while and has been utilized in different forms since olden times. Contemporary ancient references approved that the existence of ceramic water filters with safe storage elements have been extensively used in Latin America for more than 100 years and have been produced in Britain since 1850 [27]. Sutcu et al. [28] used the mixtures of clay and recycled paper waste with sawdust addition to produce anorthite refractory insulating firebrick. De Santis et al. [29] incorporated wood sawdust and sodium silicate to produce calcined clay lightweight ceramics which demonstrated to be a viable alternative to produce lightweight aggregates in structural concrete. Tiskatine et al. [30] combined the use of clay and sawdust to obtain better thermal performance in contrast with ordinary concretes. In spite of the existence of some recent local studies utilizing clay soils and sawdust for various waste containment purpose [31–33] and their effectiveness in removing heavy metals from aqueous solutions [34], an inclusive study to investigate the various clay types and saw dust with varying proportion for bacterial removal in wastewater is missing. Therefore, this study focuses on the production of low-cost ceramic filter pots from the mixture of various clay samples obtained from different sources in Ekiti State with sawdust from a typical hardwood (*Nesogordonia papaverifera*). More importantly, their suitability for household water purification in terms of microbial removal and efficiency of the ceramic filter by the rate of water flow through it were also determined.

Table 1
Coordinates of the sample location.

Sample location	Coordinates	
	Latitudes	Longitude
Ire Ekiti	7.746° N	5.399° E
Ikere Ekiti	7.499° N	5.232° E
Ara Ekiti	7.763° N	5.109° E
Isan Ekiti	7.550° N	5.190° E
Igbara-Odo Ekiti	7.504° N	5.063° E

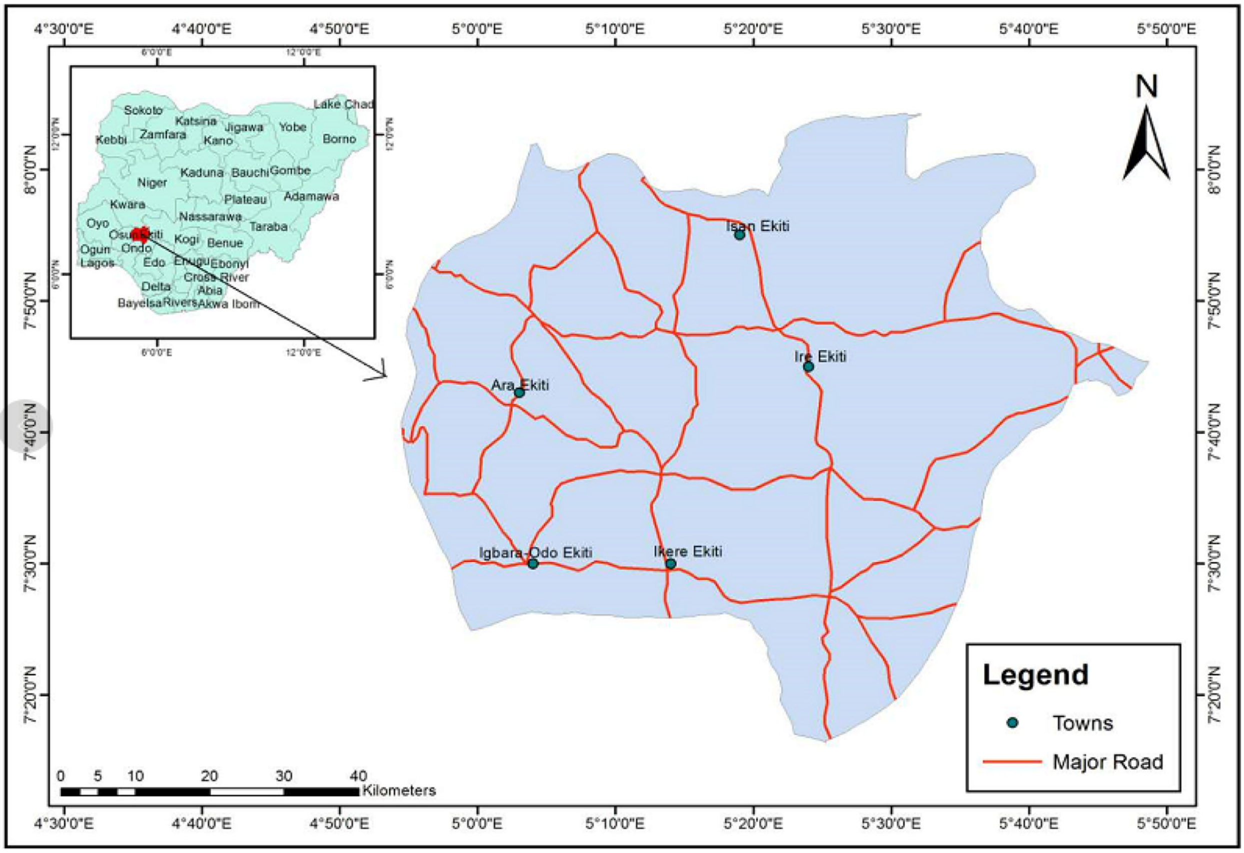

Fig. 1. Map of Nigeria showing Ekiti State with the various clay sample locations.

Materials and methods

Description of the study area

Ekiti is a State in South-Western Nigeria, rising over the sea level above 250 m. It is mainly an upland zone which lies on an area underlain by mostly rocks specifically metamorphic [35]. It is an undulating or furrow like area with a feature landscape of old plains broken step-sided out-crop that may occur singly or in groups or ridges. Ekiti State has some hills that are rugged with prominent ones known to be Ado–Ekiti Hills in the centre, Efon–Alaaye Hills on the western and Ikere–Ekiti Hills in the south. Its climate is tropical humid with two distinct seasons: the wet or rainy from April to October and the dry season (November - March). Also, it has high humidity with temperature ranging between 21 °C and 28 °C. Ekiti land is blessed with plenteous mineral deposits part of which include iron ore, baryte, aquamine granite, kaolin, columbite, channockete, limestone, among others. They are largely deposited in different towns and villages of Ado-Ekiti, Ise - Ekiti, Ijero, Ikole, and Ikere. The clay samples used were sourced from seven different points in five towns in Ekiti State which are Ire Ekiti, Ikere Ekiti, Ara Ekiti, Isan Ekiti and Igbara - Odo Ekiti as shown in the supplementary file (Figs. S1 and S2). The coordinates for each of these locations are shown in Table 1. Map of Nigeria showing Ekiti State with the various clay samples collection town is presented in Fig. 1.

Table 2
Material mixing ratios.

Clay (%)	100	90	80	70	60	50	40	30	20	10	0
Sawdust (%)	0	10	20	30	40	50	60	70	80	90	100

Sample preparation and analysis

Various clay types, sawdust which acts as combustible material and colloidal silver were the precursors utilized for ceramic filters production. The clay samples collected consist mainly of kaolin and they were labeled as Red clay from Ire Ekiti, Brown clay from Ire Ekiti, White Clay from Ikere Ekiti, Brown Clay from Igbara Odo Ekiti, Red Clay from Ikere Ekiti, Black clay from Isan Ekiti and Brown clay from Ara Ekiti using their location names for easy identification. These clay materials were utilized in this study because of its availability, low cost and minimum energy requirement in the production of ceramic filter materials. It has been reported that utilizing such materials in wastewater treatment is a feasible solution specifically when it is being used to make ceramic filters after they have been burnt [34,36]. Sawdust was sourced from a hard wood (*Nesogordonia papaverifera* of Danta Species). Sawdust was selected because it does not cause bloating and results in more uniform pore size distribution in the filters which helps to increase the porosity of the ceramic filter [8,37,38]. Equipment used are Jaw crusher, 0.25 and 0.075 mm sieves, portable Millipore membrane filter, cylindrical mould, 2–5 l covered plastic buckets and kiln. X-ray fluorescence and Atterberg limit test were carried out on the clay samples. The Atterberg limit tests which include the liquid limit, plastic limit etc. were conducted in accordance with the standard test method [39].

A laboratory scale test unit was used for the development of the ceramic pot filter. The production processes were carried out both at the Studio of the Industrial Design Department and the Mineral and Metal processing Laboratory of the Metallurgical and Material Department of the Federal University of Technology Akure, Nigeria. The different clay samples and combustible material were pulverized into small grains of about 1-inch size using Jaw Crusher and this was done in batches due to small opening of the pulverizing machine, the clay samples and combustible material were then sieved the 0.25 mm and 0.075 mm sieve size respectively.

The mixing of each powdered clay sample and combustible material moistened by the addition of water were wedged and rolled to obtain an even homogeneous mixture. The mixing was thoroughly carried out to ensure optimal material combination. The mixing of the materials was carried out in proportions known as Bi-axial blend to determine the exact ratio of clay to sawdust that will give minimum required flow rate. Table 2 shows the mixing ratio used. Aging of the clay samples was also done to cause physical changes in the material over time.

Clay mixtures were molded in small flower pot with a cylindrical shape. The molded filter materials were air dried in at average temperature of 27 °C in a dry place for 30 days to prevent material from cracking due to rapid drying or heating during the firing process. All the molded dry ceramic filters were positioned inside a kiln furnace and sintered at 877 °C to 1006 °C. Three stages of firing were observed. At the dehydration stage which occurs at a low temperature between 100 °C to 300 °C entails the elimination of excess water trapped in the molded ceramic filters. The oxidation stage which occurs between 300 °C to 500 °C, the combustible material was oxidized. The oxidation reaches 500 °C due to the properties of the clay filter elements and took over two hours to be completed before moving to the last stage which is the vitrification stage. At this stage, the constituents of the clay material began to soften and adhere into glass-like material. The temperature at which this process occurred in the kiln was between 500 °C to 877 °C. The produced filter elements were 11.80 cm in height, 8.0 cm in width, and had 1.0 cm wall thickness. The ceramic pot filter samples produced were tested for water absorption rate, flow rate, and microbial removal efficiency to determine the suitability of the clay materials used.

The absorption rates testing of all the ceramic pot filter elements were carried out to determine the rate at which the element absorbs water or become saturated. All the elements were placed in water for one hour and afterward taken out for measurement. Water sample was collected at a river in Oshinle Quarters, Akure to achieve the desired raw water coliform concentration. The choice of choosing the water sample collected was due to the intensive discharge of several waste on river side in Oshinle Quarters thereby resulting to high risk of microorganism, organic and inorganic chemical pollution in the river channel. The flow rate test was conducted in accordance with the method used by [40]. Afterward, the ceramic pot filters were filled with the raw water samples according to the standard methods for the examination of water and wastewater and the flow rate of the water was analysed by measuring the quantity of water that percolated after two hours. The water that passed through the filter pots was collected in polyethylene plastic cup for microbial analysis. Elapsed time and discharged water were then noted down on the filter log. The flow rate was computed by the division of the volume of water that flowed via the filter by the flow time. The microbial removal efficiency was ascertained employing the plate counting method. The physical properties of the various clay samples and their elemental composition has been reported in our previous study [41].

Table 3
Summary of the flow rate test.

Flow rate (l/h)	Mix ratio (Clay: Sawdust) (%)										
Material Locations	100: 0	90:10	80:20	70:30	60:40	50:50	40:60	30:70	20:80	10:90	0:100
Ire Ekiti Brown Clay	0.00	0.210	0.690	0.880	1.020	1.800	4.440	*	*	*	*
Ire Ekiti Red Clay	0.00	0.035	0.060	0.190	0.200	1.750	2.025	8.900	*	*	*
Ikere Ekiti White Clay	0.00	0.008	0.015	0.045	0.508	0.845	1.060	*	*	*	*
Ikere Ekiti Red Clay	0.00	0.035	0.050	0.080	0.195	0.200	0.800	*	*	*	*
Isan Ekiti Brown Clay	0.00	0.025	0.060	0.085	0.145	0.199	0.775	1.600	*	*	*
Ara Ekiti Brown Clay	0.00	0.003	0.014	0.085	0.185	0.600	1.475	2.000	*	*	*
Igbara Odo Brown Clay	0.00	0.340	0.550	1.290	1.450	1.900	2.300	6.000	*	*	*

Note: * means no flow as the combustible element burnt off during sintering, thereby disintegrating the materials.

Table 4
Water absorption results for all the ceramics pot filter types.

Mix ratio (Clay:Sawdust) (%)	100:0			90:10			80:20			70:30			60:40		
Material locations	W	F	S	W	F	S	W	F	S	W	F	S	W	F	S
Ire Ekiti Brown Clay	2.45	1.45	2.23	2.25	1.40	2.00	2.00	1.38	1.85	1.76	1.20	1.65	1.75	1.00	1.30
Ire Ekiti Red Clay	2.50	1.65	1.70	2.23	1.50	1.65	2.10	1.40	2.00	1.93	1.35	1.75	1.80	1.30	1.66
Ikere Ekiti Red Clay	2.60	1.85	2.20	2.03	1.50	2.00	2.10	1.44	1.82	1.63	1.30	1.60	1.40	1.23	1.50
Ikere Ekiti White Clay	2.10	1.25	2.20	1.88	0.95	2.00	1.73	0.75	1.41	1.65	0.75	1.50	1.45	0.90	1.50
Isan Ekiti Brown Clay	2.46	1.52	1.87	2.33	1.50	1.85	2.08	1.50	1.76	1.90	1.35	1.70	1.73	1.18	1.50
Ara Ekiti Brown Clay	2.65	1.65	2.00	2.45	1.10	1.32	2.38	1.35	1.56	1.88	1.00	1.25	1.81	1.00	1.19
Igbara Odo Brown Clay	2.66	1.75	2.32	2.43	1.55	1.85	2.28	1.35	1.76	1.97	1.30	1.60	1.83	1.05	1.32
Mix ratio (Clay:Sawdust) (%)	50:50			40:60			30:70								
Material locations	W	F	S	W	F	S	W	F	S						
Ire Ekiti Brown Clay	1.57	0.60	1.50	1.57	0.60	1.25	1.50	–	–						
Ire Ekiti Red Clay	1.67	1.00	1.65	1.45	0.67	1.35	1.30	0.60	1.50						
Ikere Ekiti Red Clay	1.27	1.00	1.27	1.05	0.89	1.10	–	–	–						
Ikere Ekiti White Clay	1.25	0.90	1.32	1.20	0.88	1.43	–	–	–						
Isan Ekiti Brown Clay	1.58	1.00	1.65	1.46	0.75	1.44	1.31	0.50	0.80						
Ara Ekiti Brown Clay	1.65	0.86	1.02	1.36	0.79	1.00	1.25	0.63	0.91						
Igbara Odo Brown Clay	1.55	0.85	1.15	1.46	0.70	1.00	1.33	0.62	0.89						

Note: W, F and S stand for Wet, Fired and Saturated/Saturation in 1 hr respectively.

Results and discussion

The flow rate test results for the ceramic pot filters produced at different ratios are summarized in Table 3. Their flow rates were measured based on the reduction in the water column height over a period of time. From Table 3, the values gotten vary between 0.008 l/h to 8.9 l/h per pot filter. The Ire Ekiti Brown ceramics pot filter was considered suitable for producing filter materials based on a recipe combination which varies from 60:40–40:60. Ire Ekiti Red and Igbara Odo Ekiti Brown ceramics pot filters both recorded a high flow rate as a result of high porosity of the filter elements caused by the higher percentage of the composition of the burn-out material. Their high flow rates therefore make the mix ratio not viable for the production of ceramic water filter. Although, mix ratios 50:50 and 40:60 for both ceramics pot filters gave considerably good results but can only be justified good filters based on their removal efficiencies. The Ikere Ekiti Red ceramics pot filters was unable to filter up to 1 l/h in all the varied mix ratios. This reveals the low porosity characteristics of the clay material even after firing. Therefore, the only considerable recipe to attain a minimum of 1 l/h for Ikere Ekiti Red clay will be to vary apparently the 40:60 ratio of clay to combustible material.

Water absorption test results

The water absorption rate test was conducted for each of the ceramic pot filter produced. The percentage water absorption rate was calculated as the difference between the weight of the saturated ceramic pot and the weight of fired ceramic pot divided by the weight of fired pot. It is mathematically represented in Eq. (1).

$$\frac{Weight\ of\ Saturated\ Ceramic\ Pot\ (S) - Weight\ of\ Fired\ Ceramic\ Pot\ (F)}{Weight\ of\ Fired\ Ceramic\ Pot\ (F)} \times 100 \tag{1}$$

Clay soil generally has a poor water absorption rate as its particles are tightly closed together within their structures. Tables 4 and 5 show the water absorption test results of the ceramic pot filters produced at different ratios. Eq. (1) was applied to get the water absorption rate percentages on Table 5. The ceramic filter samples produced from Ire Ekiti Brown clay at ratio 50:50 and 40:60, Ire Ekiti Red clay at ratio 40:60 and 30:70 and Isan Ekiti Brown clay at ratio 40:60 and 30:70

Table 5
Summary of the water absorption rate test.

Flow rate (l/h)	Mix ratio (Clay: Sawdust) (%)										
Material Locations	100: 0	90:10	80:20	70:30	60:40	50:50	40:60	30:70	20:80	10:90	0:100
Ire Ekiti Brown Clay	53.7	42.8	34.1	37.5	30.0	150.0	108.3	–	*	*	*
Ire Ekiti Red Clay	3.03	10.0	42.9	29.6	27.7	65.0	101.5	150	*	*	*
Ikere Ekiti Red Clay	18.9	33.3	26.4	23.1	22.0	27.0	23.6	–	*	*	*
Ikere Ekiti White Clay	76.0	110.5	80.0	100	66.7	46.7	62.5	–	*	*	*
Isan Ekiti Brown Clay	23.0	23.3	17.3	25.9	27.1	65.0	92.0	60.0	*	*	*
Ara Ekiti Brown Clay	21.2	20.0	15.6	25.0	19.0	18.6	26.6	44.4	*	*	*
Igbara Odo Brown Clay	32.6	19.4	30.4	23.1	25.7	35.3	42.9	43.5	*	*	*

Note: * means no water absorption rate was gotten as the sawdust in the ceramic mixture swell up abnormally leading to the disintegration of the materials.

Table 6
Coliform results for water filtered through all the ceramics pot filter types.

	Coliform (cfu/ml)													
Mix ratio (Clay:Sawdust) (%)	90:10		80:20		70:30		60:40		50:50		40:60		30:70	
Material locations	R_T	R_M	R_T	R_M	R_T	R_M	R_T	R_M	R_T	R_M	R_T	R_M	R_T	R_M
Ire Ekiti Brown Clay	–	–	30	59	39	50	39	50	40	49	47	42	NC	NC
Ire Ekiti Red Clay	–	–	–	–	–	–	–	–	23	66	36	53	78	11
Ikere Ekiti White Clay	–	–	–	–	–	–	300	211	54	35	68	21	NC	NC
Ikere Ekiti Red Clay	–	–	–	–	–	–	–	–	–	–	2	87	–	–
Isan Ekiti Brown Clay	–	–	–	–	–	–	–	–	–	–	300	211	300	211
Ara Ekiti Brown Clay	–	–	–	–	–	–	–	–	43	42	32	57	60	29
Igbara Odo Brown Clay	–	–	30	59	40	49	65	24	18	71	36	53	47	42

Note: R_T represents amount retained during microbial test, R_M represents amount removed during microbial test, NC: Not Considered and "-" represents nothing was retained nor removed during microbial test.

Table 7
E. coli results for water filtered through all the ceramics pot filter types.

	E. Coli (Freq)													
Mix ratio (Clay:Sawdust) (%)	90:10		80:20		70:30		60:40		50:50		40:60		30:70	
Material locations	R_T	R_M	R_T	R_M	R_T	R_M	R_T	R_M	R_T	R_M	R_T	R_M	R_T	R_M
Ire Ekiti Brown Clay	–	–	2	22	1	23	0	24	0	24	1	23	NC	NC
Ire Ekiti Red Clay	–	–	–	–	–	–	–	–	4	20	2	22	17	7
Ikere Ekiti White Clay	–	–	–	–	–	–	72	48	22	2	10	14	NC	NC
Ikere Ekiti Red Clay	–	–	–	–	–	–	–	–	–	–	29	5	NC	NC
Isan Ekiti Brown Clay	–	–	–	–	–	–	–	–	–	–	155	131	23	1
Ara Ekiti Brown Clay	–	–	–	–	–	–	–	–	13	11	10	14	15	9
Igbara Odo Brown Clay	–	–	15	9	10	14	5	19	0	24	20	4	37	13

Note: R_T represents amount retained during microbial test, R_M represents amount removed during microbial test, NC: Not Considered and "-" represents nothing was retained nor removed during microbial test.

all tend to have high absorption rates as depicted in Table 5. All these high values were on account of the high sawdust content in the mixture, as sawdust possesses high porosity. Ikere Ekiti White clay from ratio 100:0 to 70:30 exceptionally has high water absorption rate. This may be a result of clay sample constituent featured by a sandy texture. Also, Ikere Ekiti Red clay, Ara Ekiti Brown clay and Igbara Odo Brown clay all vary considerably at all ratios making them suitable when considering this property in ceramic water filter production. Generally, the water absorption test performance showed that small proportion of sawdust added adversely affects the water absorption potential ability of most of the clay samples. The results therefore reveal that increase in the percentage sawdust in the mixture increases the absorption rate and vice versa.

Microbial test results

The microbial test was carried out on each of the ceramic pot filter. The removal was determined by dividing the difference of treated water filtered and the untreated water filtered by the untreated water filtered. The microbial concentration [Coliforms and *Escherichia coli (E. coli)]* of the raw water sample taken from a river in Oshinle was determined to be 89 and 24 cfu /mL respectively. The filters produced from Ire Ekiti Brown clay sample with mix ratio 80:20 and 40:60 tends to remove high level of *E. coli* and also an appreciable level of Coliform even though some of the filters flow rate falls below 1 l/h (Tables 6 and 7). The Coliform removal from Ire Ekiti Red clay filters with 50:50 mix ratio is high compared to that Ire Ekiti Brown clay filter. Also, there was an appreciable removal of *E. coli*. The amount of coliform removed from the Igbara

Table 8
Summary of mix ratios and maximum removal of coliform and *E. coli* with respect to flow rates $\geq$ 1.

Clay samples	Mix ratios	Coliform removed	*E coli* removed	Flow-rate (l/h)
	60:40	50	24	1.020
Ire Ekiti Brown	50:50	49	24	1.800
	40:60	42	23	4.400
Ire Ekiti Red	50:50	60	20	1.750
	40:60	53	22	2.025
Ikere Ekiti White	40:60	21	14	1.060
	70:30	49	14	1.290
	60:40	24	19	1.450
Igbara Odo Ekiti	50:50	71	24	1.900
	40:60	53	4	2.300
	30:70	37	13	6.000
Ara Ekiti	40:60	57	14	1.475
	30:70	29	9	2.000

Note: Ikere Ekiti red and Isan Ekiti brown clay samples are not included in the Table as most of their flow rate values are less than 1.

Odo Ekiti ceramic filters was high for mix ratios of 50:50, 80:20, 40:60, 30:70 and low for mix ratio 60:40 while the amount of the *E. coli* removed was absolute for mix ratio 50:50. The mix ratio 70:30, 60:40 and 30:70 all have appreciable amount of removal as against mix ratio 80:20 and 40:60. A negative coliform and *E. coli* removal (i.e. increase of the amount, even after filtration) was observed for the Ikere Ekiti White clay filter with mix 60:40. Though, all other mix ratios gave positive results, the amount of coliform and *E. coli* removed are small compared to previously discussed ceramic filters. The amount of coliform removed for the Ikere Ekiti red clay with mix ratio 40:60 is high compared to Ire Ekiti Brown and Ire Ekiti Red clay filters as well as Ikere Ekiti clay filter, but with a very low amount of *E. coli* removed. Filters produced from Isan Ekiti clay sample also gave a negative result on the amount of coliform and *E. coli* removed. Though flow rate of 2 l/h was observed at a mix ratio of 30:70, the amount removed for the coliform and *E. coli* makes it unsuitable for production of ceramic filters. Subjecting the test results obtained to World Health Organization (WHO) guideline on drinking water quality, the expected total coliform concentration in drinking water is zero colony-forming-units (cfu) per 100 mL of water sample, the microbial test carried out on the entire produced filter met this requirement.

Removal efficiency

The microbial concentration test further reveals that not all the clay materials used are suitable for production of ceramic pot filters; some have properties and elements present in them that could contribute to their performance as we have in the case of Isan Ekiti clay pot filters, the results of test performed on it indicates that it is not suitable for the production of ceramic filter as its removal efficiency (Tables 4 and 5) is quite poor. On the contrary, the removal efficiency of some mix ratios of Igbara Odo Ekiti clay pot filters are very high for coliform and *E. coli* (Tables 6 and 7) which makes it a good material for the manufacture of ceramic water filters because it records 100% and 80% removal efficiencies for *E. coli* and coliform respectively specifically for the mix ratio of 50:50. Also, it was observed from the result obtained that some of the ceramic water filters samples produced, have high removal efficiency for coliform and low removal efficiency for *E. coli* and vice versa. All these are attributed to variation in mix ratio of samples and some other minerals present in the clay samples which may require higher soil testing and analysis to be detected. For proper citation, the mix ratios at which the maximum removal of coliform and *E. coli* was obtained with respect to flow rates equals to or greater than 1 l/h for the clay samples are summarized in Table 8. Figs. 2 to 8 vividly illustrate the relationship between microbial parameters (*E. coli* and coliforms) with flow rate variation from all the different clay sources. These graphical representations show the best optimum mix ratio of clay and sawdust corresponding with the maximum removed rate of coliform and *E. coli*.

Ire Ekiti brown clay ceramic filter

Ire Ekiti Brown clay ceramic filter with mix ratio 80:20 had the highest value of 66.3% and 91.7% removal efficiency for coliform and E. coli respectively (Fig. 2). The removal efficiency value for coliform and E. coli of this clay sample for different mix ratio was observed to be in descending order with mix ratio 40:60 clay pot having the least removal efficiency for both microbial parameters but with increasing flow rate value ranging from 0.21 to 4.44 l/h. This clay sample result is similar in character with the result of Franz [42], who in his study on the performance evaluation of ceramic candle water filters in Kenya obtained from local clay materials (which include test for coliphage removal) reported that Doulton Super Sterasyl filters (as they were named) have an average flow rate of 0.24 l/h in the field undiluted, but get to increase gradually in flow rate up to 5.3 l/h when some combustible additives were gradually introduced. Shuaib–Babata [43] further validates this outcome. An inverse relationship was observed to exist between the microbial parameters and the flow rate in the varied mix clay group of Ire Ekiti Brown clay sample.

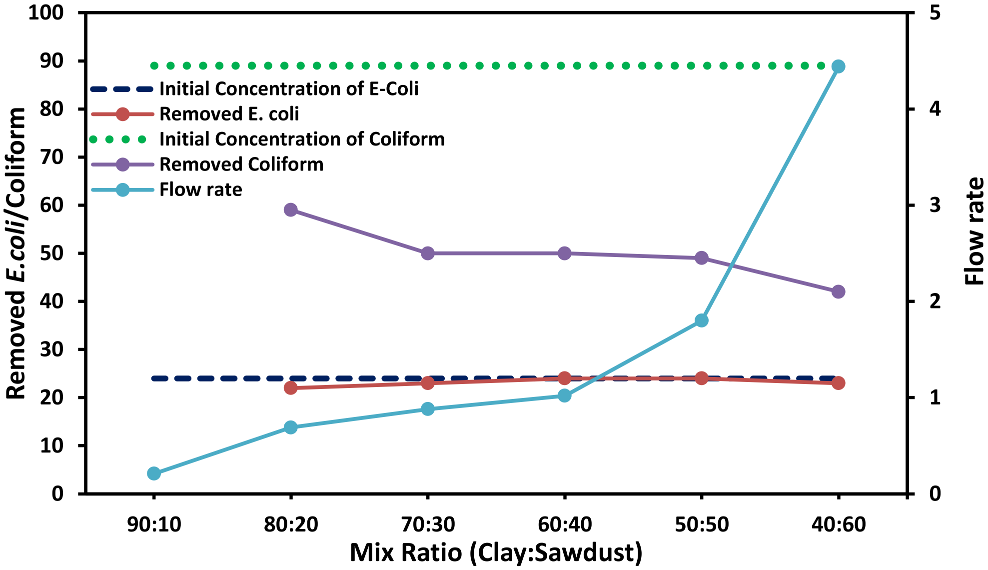

Fig. 2. Relationship of microbial parameters and flow rate variation for Ire Ekiti brown clay ceramic filter.

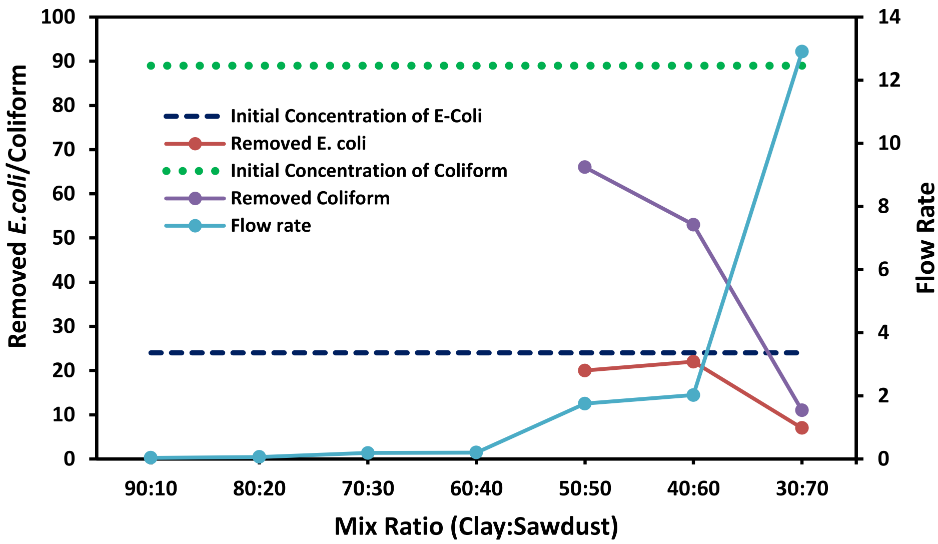

Fig. 3. Relationship of microbial parameters and flow rate variation for Ire Ekiti red clay ceramic filter.

Ire Ekiti red clay ceramic filter

The case of Ire Ekiti Red clay pot or ceramic filter was different as only three clay samples with mix ratio 50:50, 40:60 and 30:70 show removal efficiencies for coliform and *E. coli* in the water filtered. The clay sample with mix ratio 40:60 gives the best removal efficiency for *E. coli* having 91.7% followed by mix ratio 50:50 which gives removal efficiency of 83.3%. The removal efficiency for coliform gives a slightly different result as a higher degree of it was removed with clay sample 50:50 mix ratio having 74.2% removal efficiency. The clay sample with mix ratio 50:50 exhibits the best flow rate of 1.75 l/h, which falls within the recommend value of 1 to 11 l/h established by Brown and Sobsey [44] and Mwabi et al. [45] for ceramic water filters. There was observed a sudden rise in the flow rate value from 2.03 to 12.9 l/h of clay sample mix ratio 40:60 to 30:70 indicating low plasticity and high porosity of the latter clay pot. Fig. 3 depicts the representation of the removed rate of *E. coli* and coliform corresponding to the various mix ratios and flow rates

Ikere Ekiti white clay ceramic filter

Ikere Ekiti white clay ceramic filter, like the Ire Ekiti Red clay pot, has three clay samples with mix ratio 60:40, 50:50 and 40:60 showing removal efficiency for coliform and *E. coli* but only two of these mix ratios (50:50 and 40:60) gives a

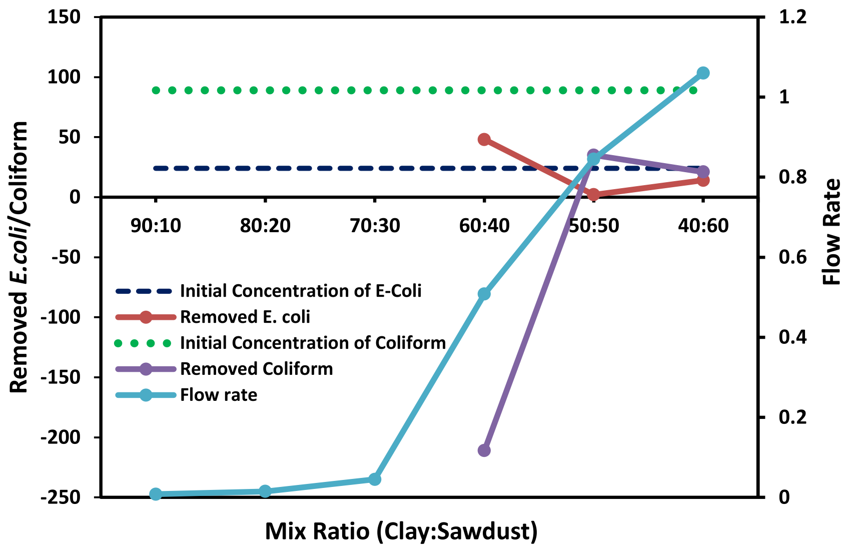

Fig. 4. Relationship of microbial parameters and flow rate variation for Ikere Ekiti white clay ceramic filter.

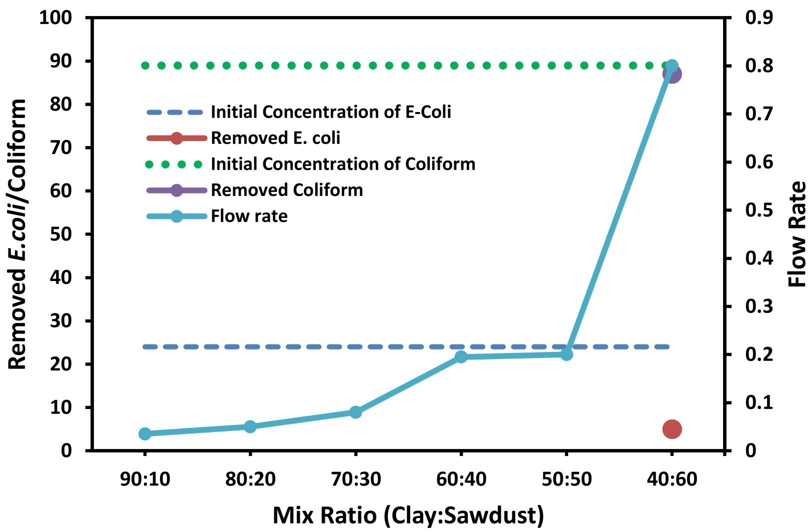

Fig. 5. Relationship of microbial parameters and flow rate variation for Ikere Ekiti Red clay ceramic filter.

positive outcome as described in Fig. 4. The removal efficiency for coliform of clay samples with mix ratio 60:40 produces a negative result. The clay sample with mix ratio 50:50 gives the best removal efficiency for coliform having 39.3%, although with low removal efficiency of 8.3% for *E. coli* and a flow rate value less than 1 l/h. Only mix ratio 40:60 has a flow rate value a bit greater than 1 l/h in the mix clay group. This result is satisfactory as it is in tandem with the study of Lantagne [46] who reported that flow rates obtained for 50% ratio of clay to sawdust in ceramic water filters are usually between 0.80 and 1 l/h during the first two hours of test. This outcome was also validated by Nnaji et al. [47].

Ikere Ekiti red clay ceramic filter

Ikere Ekiti Red clay ceramic filter barely give significant results as just the clay sample with mix ratio 40:60 gives removal efficiency of 97.8% for coliform (Fig. 5). This mix ratio of Ikere Ekiti red clay pot could barely remove *E. coli* of the initial concentration. Although, the entire mix ratio for this clay sample has flow rate values which gradually increase with decreasing amount of clay content, but with values less than 1 l/h. This result is expected as Shuaib–Babata et al. [48] in their study validate this outcome that most clay samples gotten from Ado-Ekiti and nearby local government areas like Ikere–Ekiti exhibit high plasticity but low percolation rate during filtration.

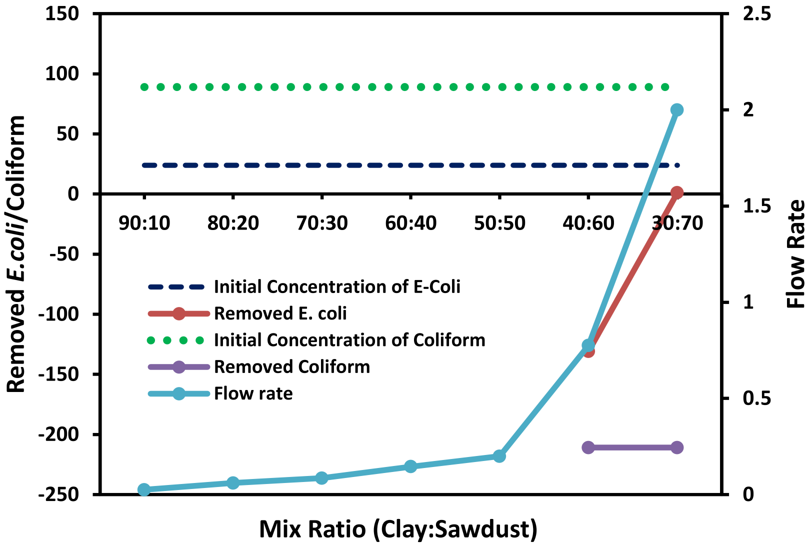

Fig. 6. Relationship of microbial parameters and flow rate variation for Isan Ekiti Brown clay ceramic filter.

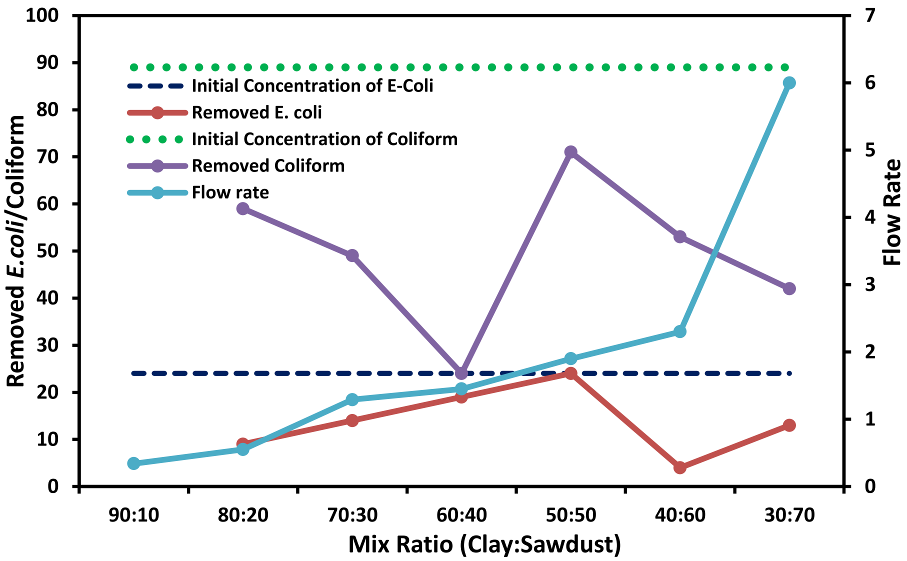

Fig. 7. Relationship of microbial parameters and flow rate variation for Igbara Odo Ekiti clay ceramic filter.

Isan Ekiti brown clay ceramic filter

Isan Ekiti Brown clay pot has a similar trend of result with Ikere Ekiti white clay pot with its two clay samples with mix ratio 40:60 and 30:70 giving negative results for both removed coliform and *E. coli* especially for mix ratio 40:60 as the removed rates at these mix ratios are portrayed in Fig. 6. The flow rate results also follow the same trend as the Ikere–Ekiti red clay pot results with only clay sample with mix ratio 30:70 having a flow rate of 2 l/h. This result reveals the high plasticity and low porosity of the clay sample type.

Igbara Odo Ekiti clay ceramic filter

Igbara Odo Ekiti clay ceramic filter gives significant and substantial outcome as all the clay mix ratios yielded positive numerical values except for mix ratio 90:10 which has no numerical result resulting from high degree of plasticity of the clay content. The mix ratio 50:50 had the highest value of 100% and 80% removal efficiency for *E. coli* and coliform respectively (Fig. 7). This was followed by mix ratio 60:40 which gives removal efficiency of 79.2% for *E. coli* although with the least removal efficiency of 30% for coliform. The flow rate results were observed to increase steadily with decreasing clay but increasing sawdust content in the mix ratios, with the values ranging from 0.34 to 6 l/h. The flow rate of the 50:50 mix

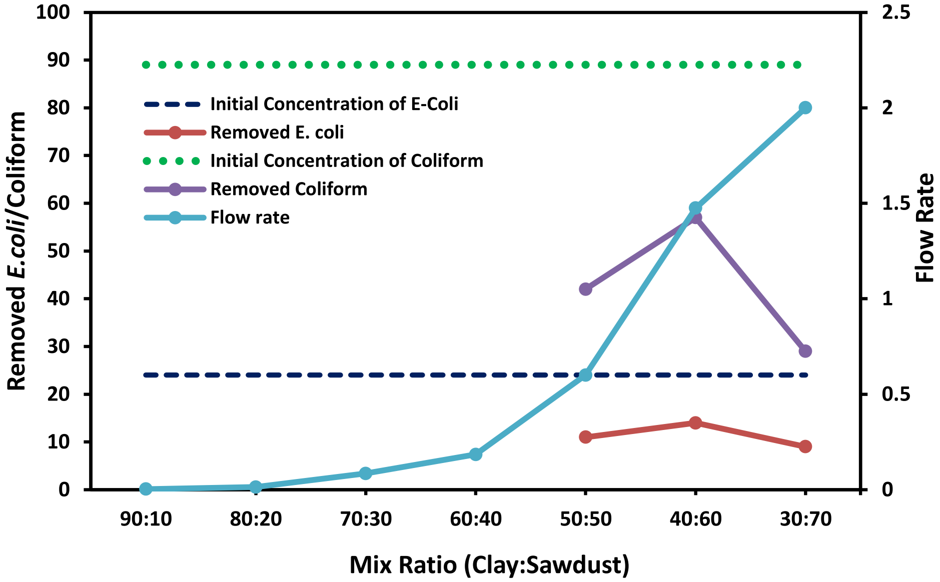

Fig. 8. Relationship of microbial parameters and flow rate variation for Ara Ekiti clay ceramic filter.

ratio sample having 100% and 80% removal efficiency for both *E. coli* and coliform is 1.9 l/h (which is an acceptable flow rate value for household ceramic water filters according to Lantagne and Clasen [17]). This mix ratio for Igbara Odo Ekiti clay therefore gives the highest removal efficiency of the two microbial parameters thus making it also the best material amidst other samples for ceramic water filter production.

Ara Ekiti clay ceramic filter

Ara Ekiti clay ceramic filter gives substantial results for only three clay samples with mix ratios 50:50, 40:60 and 30:70 for removed concentration of *E. coli* and coliform as Fig. 8 gives a pictorial view of the removed rates for the microbial parameters. The removal efficiency of *E. coli* for each of the mix were 45.8%, 58.3% and 37.5% while we have 47.2%, 64% and 32.6% for coliform. The flow rate results follow the same trend as the Ikere Ekiti Red clay pot results with only two of its clay sample with mix ratios 40:60 and 30:70 have flow rates of 1.475 and 2 l/h, respectively. Mix ratio 40:60 can be taken as the best mix in the clay group, as it yielded the highest removal efficiency of *E. coli* and coliform.

Conclusion

Ceramic water filtration has been and presently one of the topical cost-effective water treatment techniques from local materials. In this study, the ceramic pot filters produced ranging from 60:40 to 40:60, 50:50 to 40:60 and 70:30 to 40:60 for Ire Ekiti brown clay sample, Ire Ekiti red clay sample and Igbara Odo Ekiti clay sample respectively and for both Ikere Ekiti white clay and Ara Ekiti clay samples at 40:60 all showed better microbial removal efficiency. In overall, the 50% to 50% ratio of Igbara odo clay to sawdust was the most efficient and ideal mix. This was in relation with a flow rate of 1.9 l/h, removal efficiencies of 80 and 100% for coliform and *E. coli* bacteria, respectively. Therefore, production of ceramic water filters in large quantity using these clay samples will be a great achievement in redeeming and improving people's health via this cheap and viable water treatment method. The supplement of sawdust gives room to achieve insulating products by increasing the porosity but the increment in the proportion of sawdust added must not exceed 70% and not less than 30% because of a strong decrease of the mechanical strength and poor removal efficiency of microbes by the ceramic filters produced. Further research studies are required to continue the experimental analyses used in this study to enumerate removal rates of other microorganisms, such as protozoa and viruses, for distinct water feature conditions. Moreover, the field performance of locally made filters and their consequences on human health must be measured on a long-term basis.

Declaration of Competing Interest

The authors declare that there is no conflict of interest associated with this manuscript.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sciaf.2019.e00218.

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