Research Paper

Potential of ceramic and biosand water filters as low-cost point-of-use water treatment options for household use in Nigeria

Ebele Erhuanga, Maingaila Moono Banda, Doutimiye Kiakubu, Isah Bolaji Kashim, Bioye Ogunjobi, Zaid Jurji, Ibukunoluwa Ayoola and Winston Soboyejo

ABSTRACT

Many households in Nigeria lack access to safe drinking water. Sixty-three percent (63%) of the nation's population live in rural areas where only 3% of households have access to safely managed drinking water. This suggests an urgent need for intervention to offer sustainable solutions to drinking water needs at household levels. An operational research was commissioned by the United Nations Children's Fund (UNICEF) Nigeria to generate evidence to inform and guide Water, Sanitation and Hygiene (WASH) programming on household water quality. This involved an assessment of local manufacturing of household water filters; factors influencing social acceptability and market opportunities for clay and biosand water filters in Nigeria. Implementation of the research recommendations by the filter factories resulted in improved bacterial removal efficiency (>97%) in filters. Factors such as filter design and efficiency were shown to influence acceptability of filters, which influenced the price at which users were willing to pay for the filters in the study areas. The market research indicated low popularity of the filters due to lack of promotion and marketing of the water filters. The research outcomes show great potential for sustainability and marketability of clay and biosand water filters for household water treatment in Nigeria.

Key words | biosand water filters, clay water filters, household water treatment, rural and urban Nigeria, safe drinking water, UNICEF Nigeria

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HIGHLIGHTS

- The research helped identify and recommend solutions to the challenges of filter manufacturers in Nigeria.
- Design of the filters were found to influence user acceptability.
- There is no significant difference in preferences of filter users in the different geographic locations studied.
- Clay and biosand filters have good market potentials in Nigeria.
- There is great need for household water treatment systems in Nigeria.

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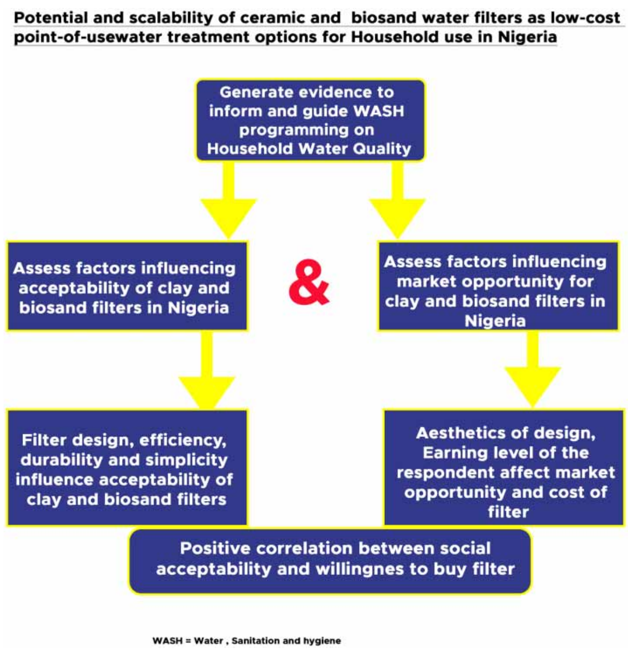
GRAPHICAL ABSTRACT



INTRODUCTION

Many households especially in the rural parts of Nigeria suffer severe lack of access to safe drinking water. Only an estimated 3.8% of rural households in Nigeria have an improved drinking water source that is free of contamination and available, within their premises (NBS & UNICEF 2017). The current estimates are presumably overstated because even when access to improved sources is available, there remains the risk of drinking unsafe water due to contamination during collection, transportation and storage (Lantagne *et al.* 2006; Kleiman 2011; Fiebelkorn *et al.* 2012; Francis *et al.* 2015; Annan 2016). This succinctly paints the picture of the water situation in the country and presses home the fact that the country is in urgent need of intervention to improve access to safe drinking water especially at the household level.

The Nigerian federal government, in 1976, created 11 river basin authorities to manage the nation's water resources. The state water corporations are responsible for the management and supply of public water. However, less than 50% of the entire population, as at 2012, is served by the piped water system. In areas where the piped water supplies are found, they are mostly intermittent, unreliable and inaccessible basically due to challenges in management and operations (NBS 2012). Virtually all urban areas in Nigeria suffer water supply shortages associated with increasing demand and infrastructural failure, especially in the face of growing population, resulting in high dependency on supplementary sources (Erhuanga *et al.* 2014). It is reported that the proportion of households in Nigeria that have access to piped water supplies had significantly decreased from 33% in 1990 to about 6% in 2015 (UNICEF & WHO 2015). Given these realities, it is necessary to extend the process of water treatment to the point of consumption at households to achieve greater productivity in national water treatment goal. The Sustainable Development Goal (SDG) target 6.1 seeks to achieve universal and equitable access to safe and affordable drinking water for all by the year 2030 (United Nations 2015); but until universal access to treated piped water is attained in Nigeria, point-of-use (POU) water treatment remains a cost-effective approach to improve the health of populations lacking access to safe water (Fiebelkorn *et al.* 2012).

Household POU water treatment has been proven to be a cost-effective means of improving drinking water quality (Lantagne 2001; Brown & Sobsey 2006, 2010; Annan 2016). The use of household water treatment methods such as boiling and application of chemical products such as chlorine and alum is well-known among Nigerian households. However, the level of adoption and uptake of POU water treatment technologies in the country is low, as implied by the 2013 Nigerian Demographic and Health Survey which reports that only 4.4% of Nigerian households use POU water treatment methods (NPC & ICF 2014). Ceramic and biosand water filters have been widely promoted as effective and low-cost technologies for household water treatment (Bielefeldt *et al.* 2009). However, the uptake and scalability of these technologies using market-driven approaches in Nigeria has not been extensively researched and documented. Some studies such as Albert *et al.* (2010) and Fiebelkorn *et al.* (2012) have reviewed factors influencing sustained adoption of POU water treatment in low- to medium-development countries. These studies suggest that sustained adoption of POU technologies is influenced by consumer behaviour, highlighting the need to understand user preferences when planning a household water treatment intervention. This informed the inauguration of this study to investigate the potential of low-cost water filters in Nigeria.

In 2017, United Nations Children's Fund (UNICEF) Nigeria commissioned a Water, Sanitation and Hygiene (WASH) operational research (OR) as part of the Sanitation, Hygiene and Water in Nigeria (SHAWN) project II, the UK Department for International Development (DFID) funded project implemented by UNICEF Nigeria. The purpose of the OR was to generate evidence to inform and guide WASH programming. The research assessed specifically issues relating to production standards, social acceptance and market opportunities for clay and biosand water filters to enhance their sustained uptake across selected communities in Nigeria.

METHODS

The action research method was designed for this study. To achieve the set-out objectives of the study, a factory assessment was carried out to evaluate the manufacturing processes and quality control protocols employed at two ceramic water filter factories: Mateng Nigeria Limited and Atamora Pottery. End-user testing was conducted through the survey method to assess user preferences and identify factors that influence consumer acceptability of the filters at the household level. A market system analysis was conducted to identify the prevailing market forces that influence the acceptability and uptake of the filters within the Nigerian context. These were to inform a process of redesign of the filter receptacles, and finally, a re-evaluation was carried out to assess the impact of the implementation of recommendations arising from the research on the production and efficiency of filters produced at both factories studied.

Factory evaluation

This evaluation investigated the quality assurance and quality control protocols of the selected factories. The objective of the assessment amongst others was to ensure that the factories' manufacturing protocols result in a consistently produced product that meets quality criteria for bacteria removal. The methods included reviewing factory-provided manufacturing process descriptions, carrying out an evaluation at the factory during production to observe manufacturing and quality control processes practised, testing of filters (before silver application) for flow rate and bacteria removal; and providing recommendations for process improvement.

Factory assessment

A questionnaire was employed in the review of manufacturing practices at the factories. The questionnaire sought information on equipment, raw materials and processing, quality control, testing, application of bactericide (silver), documentation, as well as health and safety precautions. The factory assessment also involved physical observation of the production stages. Information gathered and observations made on the factory's reported protocol were assessed against the *Best Practices* guidelines. These guidelines were developed by the Ceramics Manufacturing Working Group (CMWG) to guide the local manufacturing of ceramic pot filters (CMWG 2011).

Filter testing

Three filters that had passed all quality control evaluations but had not been treated with silver were randomly selected and tested. This is because the study was interested in assessing the efficacy of the filters without the bactericidal effect of applied silver, as a measure of quality assurance in the production processes and protocols. It is presumed that the disinfecting action of silver coating on filters will make it impossible to distinguish between the effectiveness of the silver and that of the filter pores in straining out microorganisms when tested.

The physical characteristics of each of the dry filters, including dimensions and weight, were measured and documented. The filters were tested for flow rate and the physiochemical properties of raw (influent) and filtered water were measured using a Hanna portable pH meter (HI 8424) for pH and temperature, and turbidity was measured with a calibrated Lamotte 2020 Turbidimeter. Samples of raw and filtered water were collected and tested for total coliform and *E. coli* concentrations.

Raw and filtered water samples were tested for semi-quantitative risk level using HACH® Presence/Absence (P/A) Broth with 4-methyl-umbelliferyl-β-D-glucuronide (MUG) in disposable bottles in combination with 3M™ Petrifilm (Chuang *et al.* 2011). For quality control, negative controls of boiled, buffered water were sampled. For the P/A testing, samples were incubated at 30 °C for 48 h. Colour changes within 48 h and fluorescing of samples under a long-wave UV lamp indicate *E. coli* presence at >10 CFU/100 mL. To detect bacteria levels of >100 CFU/100 mL, 1 mL of sample was pipetted on the centre of a 3M™ Petrifilm plate and the media were activated by pressing with a spreader. The plates were incubated for 48 h, and red and blue colonies with gas bubbles were counted after 24 and 48 h, respectively.

Assessment of user preferences

A social survey was carried out to determine user preferences and to identify factors that influence consumer preference and acceptability of clay and biosand filters at the household level. The survey was conducted following the deployment of clay and biosand filters to selected households in two local government areas (LGAs) each in Kaduna (Chikun and Zaria) and in Akwa Ibom states (Nsit Atai and Obot Akara). Kaduna is located in the northern part of the country, and Akwa Ibom is in the south. A total of 36 households were selected using a purposive stratified sampling technique. The various community strata were engaged to study the influence of socio-cultural environment on the perception of respondents, if any. The LGAs in each state were selected based on the possibility of finding the distinct features of rural, peri-urban and urban communities very pronounced within the LGA. Three households each were selected from rural, peri-urban and urban community in each LGA. The study areas are represented on the map of Nigeria (Figure 1) showing the states of the country wherein different aspects of the research were carried out. Figure 2 shows a drinking water

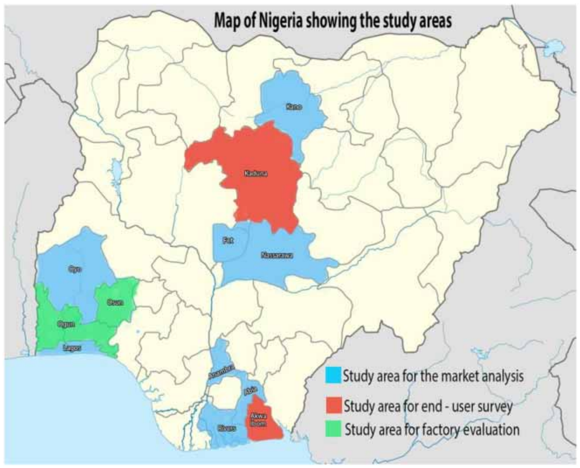


Figure 1 | Map of Nigeria showing study areas applicable to the research.

Figure 2 | Source of household drinking water in Chikun, Kaduna study area.

source for one of the households studied at Chikun LGA in Kaduna state.

Structured questionnaire, focus group discussions, observation and in-depth interview guide were used as survey instruments. The participatory rural appraisal approach was also engaged in the study, involving: direct observation and on-the-spot-checks, semi-structured interviews with key informants (mothers of households) using checklists and focus group discussion with a selected group of community elders. Ranking and scoring tools were used to generate quantitative data on respondents' preferences. The analysis of the emerging data was largely done using simple descriptive statistical tools.

Market analysis

The study area for the market analysis covered all six geo-political zones in the country. The study began with selecting one state per geo-political zone and snowballing to other states as required, depending on the nature of the study group and their relative presence or scarcity in the selected states. The selection criteria included the siting of major markets in these states (Lagos, Oyo, Rivers, Abia, Anambra, Kano and the Federal Capital Territory (FCT)); the domiciling of the filter manufacturing factories (Ogun, Osun and Akwa Ibom), as well as the study areas of the user survey.

The study groups included filter manufacturers, retailers/distributors, consumers (end users) and regulatory bodies. Purposive and snowballing approaches were actively combined to source for all study groups in these states to improve chances of finding the appropriate research population. The initial selection of the study states was based on the identification of the major markets in the country. While the snowballing method was engaged in cases where none of the study groups were found in the selected locations, referrals were sought for other locations within the region where the study groups could be found and engaged to gather the necessary data. The following states were locations where the study groups were finally engaged: Lagos, Ogun, Osun, Oyo, Rivers, Akwa Ibom, Anambra, Abia, Kano, Kaduna and the FCT.

Data were gathered by conducting key informant interviews (KII) for all the study groups, with the use of digital recording devices and interview guide. Concept testing was carried out concurrently with the KIIs, where needed. Checklist and visual materials (pictures of the filters) were used for the concept testing.

RESULTS AND DISCUSSION

The outcomes of each segment of the research were discussed and presented as recommendations to the management of the factories involved in the study. The recommendations were also used to draw up key design requirements for a redesign.

Outcomes of factory evaluation

The factory evaluation study indicated that the factories did not properly document filter production. Some surface defects were observed in a few filters, such as mould release defects, wherein the mould release material cuts deep in the filter wall during pressing, suggesting poor quality control monitoring. Poorly controlled materials and manufacturing result in inconsistently finished products. The factories confirmed this by reporting poor record keeping of production logs. Both factories also reported having poor distribution channels as well as low sales and inventory.

Filter efficiency

The initial assessment of filter efficiency at both filter factories had three filters tested. The flow rates average ranged from 1.2 to 2.8 L/h. The LRVs ranged from <1 to 1.2 for total coliform in Mateng filters and <1 to 1.4 for *E. coli* in Atamora filters, thus none of the filters tested met bacteria removal criteria of 2 LRV which is the *Best Practice* guideline value ($\geq$2 LRV) for filters before silver application. The results for both flow rate and LRV in the initial tests carried out on Mateng and Atamora filters are presented in Table 1.

Factory re-evaluation

A re-assessment of the factories' production and quality control protocol was carried out, and the filters' efficiencies were tested at a Federal Ministry of Water Resources (FMWR) reference laboratory in Akure, Ondo State,

Table 1 | Flow rate and LRV of tested clay filters

	Flow rate (L/h)		LRV	
	Test 1	Test 2	Test 1	Test 2
Mateng filters	1.2	1.5	<1.0	1.2
Atamora filters	2.5	2.8	1.0	1.4

Nigeria. This was done following the implementation of some of the recommendations based on the initial assessment of the factory as evidenced in the outcomes of the re-evaluation study. Some of the outcomes are outlined thus:

- Improved production and quality control processes are now adopted by the manufacturers.
- Manufacturing processes at the factories have been improved to produce more consistently manufactured filters that visually appear uniform, strong and well-manufactured.
- Temporary changes have been made to the design of filters as Mateng Nigeria Limited has adopted commercially available transparent receptacles based on user preferences as reported in the findings of the social survey.
- The filters' bacterial removal efficiencies (pre-silver application) were improved as a result of the implementation of quality control recommendations at the factories. Although the recommended $\geq$2 LRV was not achieved, the percentage reduction value was improved over the initial. Water quality tests on the filters were carried out at the FMWR laboratory, Akure, and the results are presented in Table 2, for the removal efficacy and Table 3 for physiochemical analysis.

The results presented in Table 3 show low effectiveness of the filters (i.e. Atamora and Mateng clay filter pots) to improve physiochemical quality of water, although the

Table 2 | Water quality test results (FMWR laboratory, Akure)

Sample ID	Filter batch no.	CFU/100 mL
Raw water sample (Atamora stream)	2,800	
Atamora (Filtered) AF	160517-008	73
Mateng (Filtered) MF	1334	45

Source: FMWR laboratory, Akure.

treatment values were in compliance with the Nigerian drinking water quality standard (NSDWQ NIS.554:2007).

Results from the social survey

The results of this survey are presented in this section and summarised in the conclusion.

The physical observations made by enumerators and field officers in the course of deploying of the filters and conducting the survey at the households are as follows:

- Hand-dug wells were observed within the premises of most households in rural and peri-urban Kaduna. This was mostly reported as the main source of drinking water among the households in those areas. However, surface water tanks were most common in Akwa Ibom, especially in the urban and peri-urban settlements. Respondents in these communities mostly reported using motorised boreholes as their main drinking water source.
- The available sanitation facilities were not sighted, though most households in the rural and peri-urban communities reported the use of pit latrines situated away from the main building.

The semi-structured interviews engaged checklists administered to key informants. The socio-economic characteristics of the respondents in the study areas are presented in Table 4. These highlight the age, educational level, occupation and earnings of the key informants, as well as the size of the family they represent.

Several factors were investigated into using the questionnaire and checklist as tools. The outcomes of the responses received are presented and discussed further.

Source of drinking water of the households under survey

Many households ($\geq$50%) in the urban communities in both states reported motorised boreholes as their main source of drinking water. Only a small fraction of the urban dwellers had access to pipe-borne water either on premises or in public spaces. None of the households in the rural and peri-urban communities studied had access to piped water supplies. This is mostly due to lack of piped water connections in these locations. Cart water was found to be a common source of

Table 3 | Physiochemical analysis of filter-treated water samples

Sample ID unit	pH	Turbidity (NTU)	Colour (Pt/Co)	Conductivity (μs/cm)	Alkalinity (mg/L)	Total hardness (mg/L)	Magnesium hardness (mg/L)	Calcium hardness (mg/L)
NSDWQ NIS.554:2007	6.5–8.5	5	15	1,000	500	150	75	75
Raw Water Sample (Stream)	6.90	20	254	186	20	72	18	54
Atamora (Filtered) AF	7.05	5	111	216	20	62	18	44
Mateng (Filtered) MF	6.30	2	27	188	6	36	10	26

Source: FMWR laboratory, Akure.

Table 4 | Socio-economic characteristics of respondents

	Urban area		Peri-urban area		Rural area	
Socio-economic characteristics	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
Age in years						
41–50	2	16.7	4	33.3	4	33.3
51–60	4	33.3	4	33.3	4	33.3
Above 61	6	50.0	4	33.3	4	33.3
Total	12	100	12	99.9	12	99.9
Household size						
0–5	8	66.6	4	33.3	Nil	Nil
6–10	2	16.7	2	16.7	8	66.6
11–15	2	16.7	2	16.7	Nil	Nil
>16	Nil	Nil	4	33.3	4	33.3
Total	12	100	12	100	60	99.9
Education attained						
Quranic school/vocational school	Nil	Nil	1	8.4	2	16.7
Completed primary school	2	16.7	2	16.7	4	33.3
Completed secondary school	2	16.7	3	25.0	2	16.7
Tertiary	8	66.6	6	50.0	4	33.3
Total	12	100	12	100.1	12	100
Occupation of respondents						
Self employed	4	33.3	4	33.3	2	16.7
Farmer	2	16.7	2	16.7	6	50.0
Public servant	2	16.7	4	33.3	Nil	Nil
Retired	4	33.3	2	16.7	2	16.7
Others	Nil	Nil	Nil	Nil	2	16.7
Total	12	100	12	100	12	100
Monthly income of respondents						
≤50,000	4	33.3	1	8.4	8	66.6
51,000–100,000	4	33.3	6	50.0	3	25.0
>101,000	4	33.3	5	41.6	1	8.4
Total	12	99.9	12	100	12	100

drinking water supply among respondents in rural Kaduna state. The quality of this water source is uncertain and usually considered unsafe. Unprotected hand-dug wells were the most common source of drinking water reported in rural and peri-urban Kaduna. It is noteworthy that a reasonable percentage of the respondents in rural and peri-urban, Akwa Ibom state reported surface water as their main drinking water source. This is akin to the situation in Kaduna and shows that there is a need to create access to improved and safe water especially in these communities. The response distribution for drinking water sources is presented in Figures 3 and 4.

Ownership of drinking water source

A 100% ownership and management of drinking water sources by individual households were reported in rural

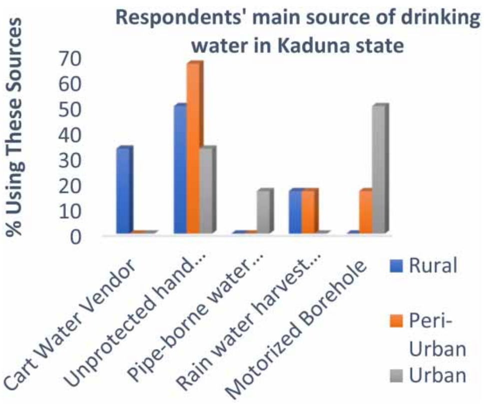


Figure 3 | Main source of drinking water distribution of respondents in Kaduna.

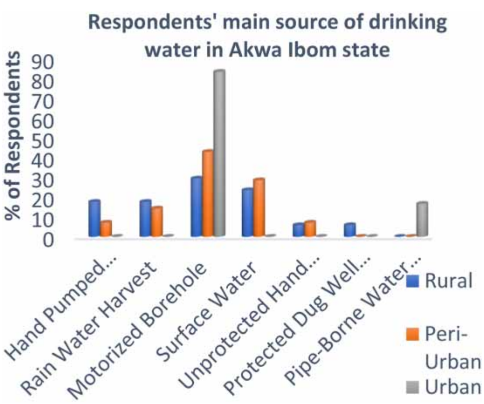


Figure 4 | Main source of drinking water distribution of respondents in Akwa Ibom.

and peri-urban Kaduna as well as in urban Akwa Ibom state. Government ownership of water sources was only reported among 50% of respondents in urban Kaduna, while respondents in Akwa Ibom reported no government involvement in the management and supply of their drinking water. The use of community-owned water sources was reported by >30% of respondents in rural and peri-urban Akwa Ibom. This most likely refers to the surface water supply reported as the main drinking water source among some respondents in those communities.

Distance to main water distribution of respondents

Most respondents in Kaduna state reported they spent 15 min or less to access their main water source. This includes 100% of the respondents in the rural community and 50% of respondents in both the peri-urban and urban communities. This may be unrelated to the fact that most of respondents use unprotected hand-dug wells on their premises as their drinking water source. The 16.7% of urban respondents that reported $\geq$60 min distance to the water source might be those that reported using piped water supply within the public sphere as their source of drinking water. Respondents in Akwa Ibom state reported that 100% of the urban households have $\leq$15 min walking access to their drinking water source as well as a majority of rural (83%) and peri-urban (67%) households.

Treatment of the drinking water distribution of respondents

All the households studied in rural and urban Kaduna and 83.3% of peri-urban households reported not treating their water in any way before drinking. 16.7% of the peri-urban households reported treating their water by boiling. Although the use of filters is unfamiliar among all respondents in Kaduna state because they reported not seeing them before, it could prove to be a lower cost method of treating their water than boiling. However, some respondents in Akwa Ibom state reported treating their water in some way before drinking. The details are presented in a chart (Figure 5).

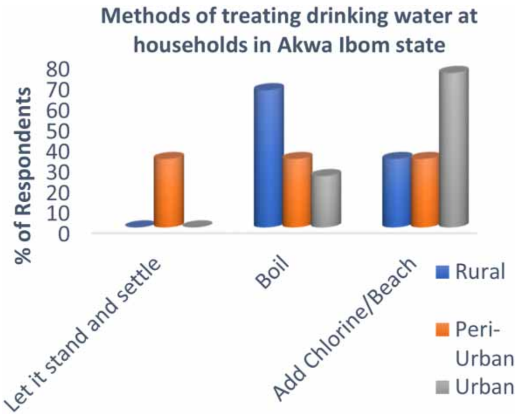


Figure 5 | Methods of treating drinking water distribution of respondents.

Available household sanitation facilities distribution of respondents

None of the respondents from all the communities in the study areas reported practising open defaecation. Most of the respondents (≥50%) from rural and peri-urban communities in both states reported using pit latrines with or without cover slabs. The majority of the respondents in urban communities of both states reportedly use water closets.

The reports on the outcome of the focus group discussions engaged in the study areas are highlighted thus:

- The discussions confirmed the fact that ownership and management of water sources for households were mostly private. They decried the situation where individual families were responsible for sourcing for their water supplies, and in most cases, at very high costs.
- The group identified malaria as the major health issue of concern in the communities studied. They reported that diarrhoea rarely occurred; however, they could not confirm the incidence rate of diarrhoea within their communities.
- The group also pointed out that opaque receptacles were not desirable because they did not allow for the visual cues to the water level which will prompt the refilling of the filters. They also recommended that the filter units come with stands that could make it more convenient to use, especially in households with limited space.

The ranked responses were used to analyse the relationship between variables, determine agreement among respondents and analyse user preferences.

Results of *t*-test at 5% significance, analysing user preferences of filter types

The outcome of aspects of the questionnaire distribution which indicates preference was analysed using *t*-test statistical method. Responses on any two of the filters were analysed per test and are presented in Tables 5–7.

In summary, these results showed that the users had a preference for the design of Atamora clay filters over the Mateng filters and biosand filters. There was also found to be no significant difference between user preferences for the Mateng clay filters and the biosand filters. The Atamora and Mateng ceramic water filter units are shown in Figures 6 and 7 respectively, while the biosand water filter system can be seen in Figure 8.

Table 5 | Comparing user preferences for Mateng and Atamora clay filters

S. no.	Variables/questions	Mateng	Atamora	*P*-value
1	Likeness of filter design	2.50 ± 0.19	3.89 ± 0.25	0.000
2	Likeness of filter size	2.89 ± 0.25	3.02 ± 0.27	0.707
3	Likeness of filter material	3.00 ± 0.25	3.94 ± 0.19	0.004
4	Meeting household demand for volume	2.67 ± 0.25	2.83 ± 0.24	0.634
5	Meeting household demand for treatment	3.16 ± 0.25	3.61 ± 0.23	0.189

P-value ≤0.05 is significant.
Note: Values are presented as Mean ± S.E.

Table 6 | Comparing user preferences for Atamora clay filter and biosand filter

S. no.	Variables/questions	Atamora	Biosand	*P*-value
1	Likeness of filter design	3.89 ± 0.25	2.50 ± 0.25	0.000
2	Likeness of filter size	3.02 ± 0.26	2.44 ± 0.21	0.097
3	Likeness of filter material	3.94 ± 0.19	2.55 ± 0.23	0.000
4	Meeting household demand for volume	2.83 ± 0.24	2.83 ± 0.25	1.000
5	Meeting household demand for treatment	3.61 ± 0.23	2.56 ± 0.23	0.002

P-value ≤0.05 is significant.
Note: Values are presented as Mean ± S.E.

Table 7 | Comparing user preferences for Mateng clay filter and biosand filter

S. no.	Variables/questions	Mateng	Biosand	*P*-value
1	Likeness of filter design	2.50 ± 0.20	2.50 ± 0.25	1.000
2	Likeness of filter size	2.89 ± 0.25	2.44 ± 0.22	0.187
3	Likeness of filter material	3.00 ± 0.26	2.56 ± 0.23	0.200
4	Meeting household demand for volume	2.67 ± 0.25	2.83 ± 0.24	0.638
5	Meeting household demand for treatment	3.17 ± 0.25	2.56 ± 0.23	0.073

P-value ≤0.05 is significant.
Note: Values are presented as Mean ± S.E.

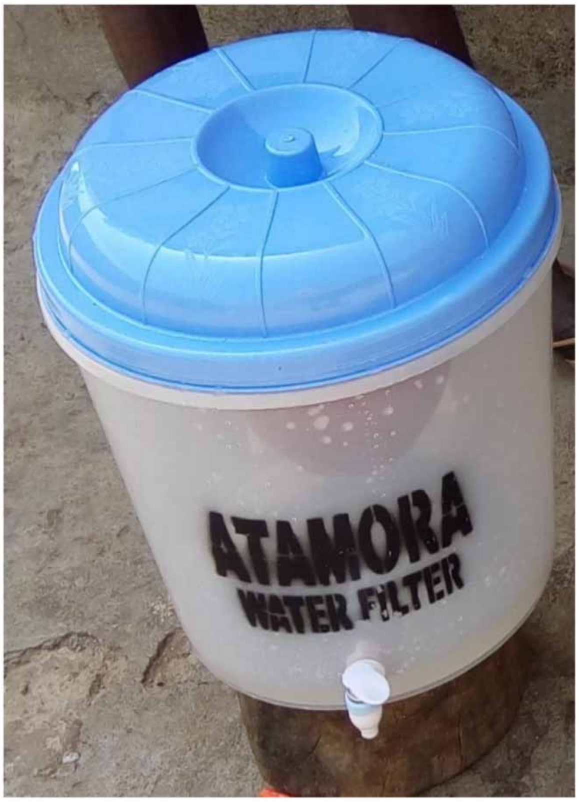


Figure 6 | Atamora water filter unit.

Figure 7 | Mateng water filter unit.

Figure 8 | Biosand water filters system.

The ANOVA test method was applied to compare user preferences in all three filters (Mateng, Atamora and biosand). The test revealed that there were significant differences in user preferences for the designs of the three filters and their ability to meet treatment demands (improve physical properties in filtered water). However, the Duncan test for homogenous subsets showed that the respondents were majorly indifferent about the design of the Mateng and biosand filters, hence the preference for Atamora filter design. The Atamora filter material was also more preferred than the other two filters. This response may be unconnected to the fact that the Atamora filter receptacles are translucent, giving the desired visual cue to the level of water, as mentioned in the focus group discussions. Users in the study areas considered the ceramic filters (Atamora and Mateng) better at improving the physical quality of water such as colour, taste and odour than biosand filters. The results are inserted in the Supplementary Appendix section.

Assessment of factors that affect acceptability

Pairwise correlation was used to assess the factors that influenced acceptability of the filters within the study areas. The correlation between acceptability and willingness to pay among users in the study areas is presented in Table 8. There was shown to be positive correlation between the users' acceptability of the filters and their willingness to pay.

Kendall's *W* test for concordance was used to assess the agreement between responses on acceptability of filters in the two states studied. The results presented in Table 9 show that there was some level of agreement among respondents on acceptability and willingness to pay for the filters across the varying community strata studied.

Pairwise bivariate correlation was engaged in assessing the relationship between some of the factors studied. The results are presented in Table 10. Factors such as design (aesthetics), simplicity of operations (ease-of-use), efficiency and strength were found to be positively correlated with acceptability of the filters among users in the study area. Acceptability was also found to correlate positively with the willingness to pay for the filters among users. The earnings of the respondents were shown to influence the price at which they were willing to buy the filters.

The factors found to influence acceptability of the filters in the study areas are summarily presented in Figure 9.

Table 8 | Correlation between acceptability and willingness to pay among users

		Pearson's correlation		Kendall's *W*	
S. no.	Community/settlement	Corr. coeff. value	*P*-value	Coff. of concordance	Asymp. Sig.
1	Rural Kaduna	0.617[b]	0.006	0.409	0.007
2	Peri-urban Kaduna	0.563[a]	0.015	0.611	0.001
3	Urban Kaduna	0.855[b]	0.000	0.148	0.102
4	Rural Akwa Ibom	0.632[b]	0.005	0.045	0.366
5	Peri-urban Akwa Ibom	0.746[b]	0.000	0.000	1.000
6	Urban Akwa Ibom	0.662[b]	0.003	0.356	0.011

[a]Correlation is significant at the 0.05 level.
[b]Correlation is significant at the 0.01 level (2-tailed).

Table 9 | Agreement between respondents in the different community strata studied in Kaduna and Akwa Ibom states on filter acceptability and willingness to buy

		Kendall *W*-statistic concordance	
S. no.	Community/settlement	Coeff. value	Asymp. Sig.
1	Acceptability in Kaduna communities (rural, peri-urban and urban)	0.282	0.006
2	Acceptability in Akwa Ibom communities (rural, peri-urban and urban)	0.710	0.276
3	Willingness to pay (WTP) in Kaduna communities (rural, peri-urban and urban)	0.384	0.001
4	Willingness to pay (WTP) in Akwa Ibom communities (rural, peri-urban and urban)	0.158	0.058

Market system analysis

The result of the market system analysis is drawn from the assessment of responses the different categories of respondents (i.e. filter manufacturers, retailers/distributors, consumers and regulatory bodies) on the design and operational concept of the clay and biosand filters.

Sources of domestic water used by the respondents in the study areas engaged in the market survey show that motorised boreholes and piped tap water were mostly used. This is because most of the markets identified for the study are sited within major cities in the country and as such, classified as urban settlements, and these may be mostly considered as priority areas by government for water supply because of the population such markets attract. Figure 10 depicts the distribution of main water source of respondents in the market surveyed areas.

About half of the respondents reported that they have neither seen the clay nor biosand water filters before. The biosand filters were preferred to the clay filters in the

Table 10 | Correlation between factors investigated to acceptability of filters among users in the study areas

S. no.	Factors/variables	Pearson's correlation: Corr. coeff. value	Pearson's correlation: P-value
1	Influence of filter design on its acceptability among users	0.491[b]	0.000
2	Influence of perception of meeting water treatment needs (efficiency) on acceptability of filters	0.403[b]	0.000
3	Influence of likeness of filter material (signifying strength and durability) on acceptability of filters	0.408[b]	0.000
4	Influence of operational simplicity of filters on its acceptability	0.424[b]	0.001
5	Influence of acceptability on the price/ willingness to pay for the filters	0.711[b]	0.000
6	Influence of likeness (preference) of filter design on the price/willingness to pay	0.550[b]	0.000
7	Influence of perceived efficiency (meeting household treatment demands) of filters on the willingness to pay	0.547[b]	0.000
8	Filter size (preference) and perception of meeting household demand in terms of volume	0.904[b]	0.000
9	Influence of monthly income on the price users are willing to buy Mateng filters	0.714[b]	0.000
10	Influence of monthly income on the price users are willing to buy Atamora filters	0.754[b]	0.000
11	Influence of monthly income on the price users are willing to buy biosand filters	0.362[a]	0.030
12	Influence of time/distance from water source on users' willingness to buy Mateng filters	0.241	0.156
13	Influence of time/distance from water source on users' willingness to buy Atamora filters	0.485[b]	0.003
14	Influence of time/distance from water source on users' willingness to buy biosand filters	0.095	0.582

[a]Correlation is significant at the 0.05 level.
[b]Correlation is significant at the 0.01 level (2-tailed).

Figure 9 | Factors that influence acceptability of filters among users in the study area.

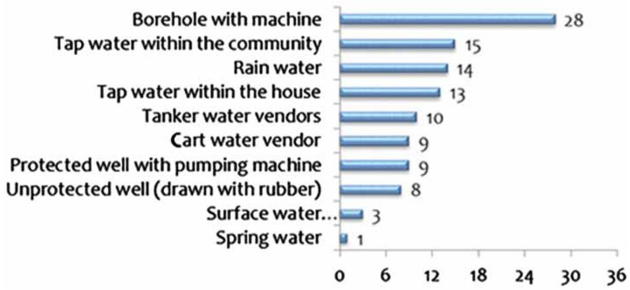


Figure 10 | Main source of drinking water distribution for consumers in market surveyed areas.

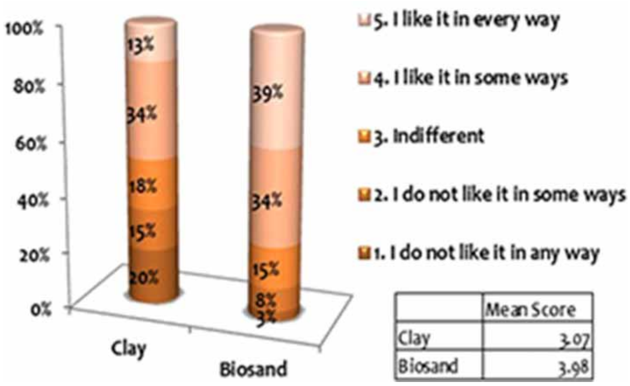


Figure 11 | Preference distribution for clay and biosand filters among consumers.

study areas when comparing the mean score of ranked responses, as shown in Figure 11. The response distribution of the concept testing is summarised in Table 11.

It is noteworthy that though most respondents perceived the clay filter to be easier to use than the biosand filter, the latter was still the preferred filter in the study areas. While people are not in doubt of the effectiveness of the filters, they are sceptical that it may not sufficiently meet the

Table 11 | Summary of the concept test

Checklist points	Clay filter	Biosand filter
Have not seen the filter before	56%	46%
Likeness and likelihood to buy		
Like the filter very much	21%	48%
Very likely to buy the filter with money	21%	57%
Willingness to pay (WTP)		
Average price consumers are willing to pay	2,996	8,690
Amount most mentioned by consumers	N3,000	N3,000
Operational description		
Operation of filter seems simple	97%	43%
Filter may be easy to maintain	52%	48%
Perception of effectiveness and meeting of needs		
Filter will be effective	57%	89%
Filter may sufficiently meet household volume demand	33%	67%
Filter appearance		
Like the filter in every way	13%	39%
Design is simple	87%	66%
Filter is attractive	20%	48%
Filter design		
Colour is acceptable	64%	87%
Shape is acceptable	46%	89%
Size is acceptable	36%	90%
Texture is acceptable	48%	74%
Material is acceptable	46%	74%
Packaging is acceptable	44%	70%
Perceived challenges with use of filters		
Will likely discharge water slowly	26%	10%
May easily break	61%	20%
Tap will possibly leak	28%	21%
Cover may not fit tightly	16%	13%
The filter may be difficult to clean	8%	46%

household needs especially in terms of volume. Many of the respondents do not find the filter designs attractive. The anticipated challenges with using the filters include slow discharge of water, low durability of the receptacles and difficulty in cleaning the filters.

The distributors cited poor access to the supply chain as a challenge. There is not much to promotion and marketing of the water filters by the retailers and distributors due to the low popularity of the filters. Distribution channels of water treatment products in Nigeria are reportedly very weak, and the products are driven by the demand of the end users. Users of household water treatment products were reported to generally make their choices from the few available water filters in the market. It was observed that some foreign products are currently in the markets and they seem to be often preferred by the consumers.

Lastly, the study groups in the market survey listed limitation with transportation, insufficient capital to expand, low-level technology and poor government involvement in the manufacture and distribution of household water treatment products as challenges faced. It was indicated in the market study that the biosand filter was preferred to the clay filter in the study areas.

CONCLUSION

The implementation of the recommendations, generated in the course of the factory evaluation studies, resulted in improved consistency in production and quality control processes, and greater bacterial removal efficiency (>97%) in the filters.

The social survey revealed that the general design and visual appeal of the filters have significant influence on its acceptability among users in the communities studied. Acceptability was influenced not only by the users' design preferences but also by a perception of efficacy and durability of the filters. The user acceptability of the filters was also found to correlate positively with their willingness to buy the filters. This was reflected in the price at which the users were willing to pay for the filters. The earnings of the users were as well shown to influence the price at which they were willing to buy the filters.

The research has demonstrated that clay and biosand filters have a great potential for sustainability in many parts of Nigeria. The concerns raised by respondents in the study border on aesthetics, basic ergonomics and availability.

The redesign study took into consideration feedback from the social survey and the market system analysis and has brought forth a receptacle design which is currently at the validation stage. However, Mateng filters have temporarily adopted a commercially available receptacle in response to the research outcomes. The factories are relentlessly working to improve manufacturing and quality control processes to achieve the required minimum ≥2 LRV effectiveness in filters.

Conclusively, with the local availability of raw materials for filter production and a proven consumer willingness to buy at prices that are not austere for factories to engage in profitable production, there is great potential for sustainability of these technologies amongst existing and new manufacturers. This also points towards greater marketability of the products and as well holds great promise for economic activity for local potters thereby enhancing job creation. Above all, this would go a long way to meet the need for increased and improved access to safely managed water for households in Nigeria.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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