



The Use of Biosand Filter as an Alternative for Safe Rural Water Supply

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ABSTRACT

Adequate and easily accessible water that meets safety standards is paramount for safeguarding public health, regardless of its intended use. However, ensuring access to a reliable and safe water supply remains a considerable challenge, particularly in developing countries, especially within rural regions. In these areas, individuals often source water from unprotected reservoirs and utilize it without proper treatment, exposing themselves to significant health hazards. To address this pressing issue, the study employed the Biosand Water Filter (BSF) as a solution to examine its effectiveness in providing portable and safe water. The study involved treating water samples from three distinct sources—Stream, Hand Dug Well, and Borehole—using three different BSF systems. The subsequent assessment encompassed the analysis of both untreated and treated water samples using established standard methods. The results of the study are compelling. Notably, there was a complete removal of *Escherichia coli* from all three water sources. Additionally, the elimination rate of total coliforms was 100% in the Borehole water source and approximately 97% and 98.21% in the Stream and Hand Dug Well sources, respectively. Further analyses revealed a complete removal of various particulate matters, including color, turbidity, and iron, from the Borehole water source. Conversely, the average percentage removal of color was 97.23% and 91.05% for the Stream and Hand Dug Well sources, respectively, while turbidity showed removal rates of 96.45% and 98.85%, respectively. Nevertheless, the study noted an increase in the concentration of certain parameters. The average pH values experienced an increment of 6.19%, 11.31%, and 11.58% for the Stream, Hand Dug Well, and Borehole sources, respectively. Similarly, the average electrical conductivity (EC) values displayed increments of 68.71%, 43.64%, and 70.41% for the Stream, Hand Dug Well, and Borehole sources, respectively. The average total dissolved solids (TDS) values also saw increases of 69.01%, 43.52%, and 52.15% for the Stream, Hand Dug Well, and Borehole sources, respectively. In contrast, average total alkalinity values showed increments of 71.69%, 40.22%, and 52.15% for the Stream, Hand Dug Well, and Borehole sources, respectively. These increases in parameter concentrations could potentially offer health benefits to individuals with gastrointestinal conditions within the targeted population. Based on the study's findings, the Biosand Water Filter (BSF) emerges as a promising alternative for providing safe water supply within rural areas. The study underscores the potential of this solution to effectively mitigate health risks associated with untreated water, especially in regions where access to clean water remains a challenge.

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INTRODUCTION

The significance of access to safe water and effective sanitation is fundamental for any developmental transformation and

contributed to the overall achievement of the Millennium Development Goals (MDGs) and is requisite for the Sustainable Development Goals (SDGs). Water Quality is a requisite and

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vital to the social, health and economic wellbeing of people. The social, health and economic wellbeing of people are undoubtedly dominant factors that determine food security. Improved water supply, hygiene and sanitation can boost countries' economic growth and contribute greatly to poverty reduction (WHO, 2023). Furthermore, the author reported that globally 368 million people take water from unprotected wells and springs and 122 million people collect untreated surface water from lakes, ponds, rivers and streams. Water supply infrastructures are poorly developed or maintained, or are non-existing in most rural areas of developing countries (Mangoua-Allai et al, 2012). Olawale, et al. (2020) stated that Sub-saharan African countries has inadequate sustainable water supply systems, due to widespread water supply infrastructural mismanagement and continuous breakdowns, eventually leading to scarcity of safe water. The author further said, millions of Nigerians particularly those in rural areas, depends on unprotected surface water sources for drinking and domestic use due to inadequate sustainable safe water sources. Sustainable and equitable access to safe drinking water remains a challenge in Nigeria, with up to 87% (179 million) of Nigerians do not have access to safely managed drinking water services (FMWR et al, 2021). Access to safely managed drinking water supply services remains inadequate in the North, with the Northeast having the lowest access at 2%, while the Southwest has the highest at 29%. Access for the rural population is at 6%, about four times lower than access levels for the urban population at 27%. There are also notable differences in access between the richest and poorest households. The poorest households has only 2% access and are about 18 times less likely to have access to safely managed water services than the richest households with 37% access.

Typically, people in rural areas collect water from any available source and store in a vessel at home for domestic use including drinking, without treatment and protection from further contamination (Guchi, 2015). This attitude subject rural populations to great risk of ingesting unclean water contaminated with microbes from human and/or animal faeces (Guchi et al, 2014). Hence the need of appropriate technology for remedial action

become imperative. Point-of –use (PoU) water treatment and safe storage technologies at the household level offer a solution to consuming and usage of unsafe water. PoU technologies allows people with access to only unsafe water sources to treat water by themselves at their convenience (Stauber *et al.* 2006). Several PoU technologies are used to improve the quality of water, which includes filtration, distillation, chemical disinfection, reverse osmosis, sunlight disinfection and use of water purifiers (Nair & Mansoor, 2014); Hogarh, et al., (2015). Any of these PoU technologies can decrease the risks of water borne diseases transmission (Andreoli & Sabogal-Paz, 2020).

Filtration process by using fine sand with low filtration rate removes the turbidity by physical and biological processes (Fitriani et al. 2014). The most effective removal compartment of a slow sand filter (SSF) system is the Schmutzdecke ('dirt cover' in German), a biofilm-like layer developing on top of the sand filter bed in which more than 90% of pathogen indicator bacteria and coliphages are retained (Pfannes, et al., 2015). Biosand Filter (BSF) as the most promising PoU filtration technology, is a household scale, intermittently operated SSF. A single BSF integrates several of treatment technologies (sedimentation, filtration and disinfection) into a single unit. This integration improves and provide the best water quality possible within an affordable and sustainable means (Janjaroen, 2016). The BSF is an adaptation of the traditional slow sand filter, which can be used for community water treatment. Pathogens and suspended solids are removed through a combination of biological and physical processes that take place in the biolayer and within the sand layer. These processes include: mechanical trapping; predation; adsorption and; natural death (CAWST, 2012a). BSF is one of the commonly used household purification technology in rural areas of developing countries, currently used in 60 countries (CAWST, 2012b). Health impact studies in different countries have shown that the use of BSF results in 20–50% reduction in diarrhoeal diseases (Nair, et al., 2014). BSF is suitable for use in rural areas because it is cheap to construct and maintain, requires no energy and/or chemical to operate and gives visibly clear treated water (Mahlangu, et al., 2011); O'connell, et al., (2023). A water

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treatment system capable of removing contaminants from water in a single filtration process, cheap and easy to maintain is considered an alternative for providing safe clean water in rural areas. Hence in Nigeria, the indispensable benefits of BSF might make it appropriate technology for rural water supply and boosting of access to safe drinking water coverage.

MATERIALS AND METHODS

Installation and Operation of Biosand Filter

Installation and operations of the BSF were conducted according to the manufacturer’s specification. Three sets of BSF systems were installed for the study. Indigenously developed BSF manufactured by GEEPEE Industries Ltd with the support of CAWST was used for the study. The filter

container (plastic cylinder) was cleaned and clear water was added to check for leakage. The drainage gravel, separation gravel and filter media were respectively poured into the filter container. Addition of 20 litres clean water between placements was carried out to ensure layer uniformity, as well as the gravels and the BSF were well submerged in water. Filter was recharged with sample water to be treated on daily basis for 25 days, for full biofilm development. After full formation of the biofilm, the three installed BSF systems were operated with Mando – Rigasa stream water source, Farin gida community hand dug well water source and NWRI main borehole water source respectively on daily basis. After each BSF operation, raw and treated water were analysed daily for each water source and results were recorded.



Figure 1 – 6: Mando – Rigasa stream, Farin gida hand dug well and NWRI main Borehole sampling site and corresponding BSF system respectively.

Raw and Treated Sample Analyses

Raw and treated water samples were analysed for physical, chemical and microbiological parameters related to the BSF treatment function and values obtained were compared with the Nigerian Standards for Drinking Water Quality (NIS-554-2015) and World Health Organization maximum permissible guidelines (WHO, 2012). The analytical methods adopted were based on international acceptable methods and analytical application principles. The principles employed were all based on approved standard methods for water and wastewater examination (APHA-

AWWA-WEF, 2017) and strictly adhered to. Summary of procedure used for testing each of the parameter is given below.

Acidity and Alkalinity Intensity (pH) analysis was conducted by APHA 4500-H⁺ B (Electrometric using glass electrodes Micro 800 Multi-parameter meter). The electrode was dipped into the water sample at about 2 – 3cm, stirred once and reading allowed to stabilize. Calibration of the pH meter was conducted at three points using pH 4, 7 and 10 standard solutions before sample analysis.

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Electrical Conductivity and Total Dissolved Solids were analysed by APHA 2510 B (Electrometric using glass electrodes Micro 800 Multi-parameter meter). The Conductivity probe measures both conductivity and Total dissolved solids (TDS) of sample. The testing were conducted by submerging the probe into the water sample in a plastic beaker to minimize any electromagnetic interference, stirred once and reading allowed to stabilize. Calibration of the EC/TDS meter was conducted on a daily basis using compatible EC standard solution (12.88mS/cm).

Colour was measured by APHA 2120 B (Visual Comparison) using Lovibond comparator with permanent colour disc ranging from 0 to 50 scales. Two sample cells was filled to the mark with distilled water and sample water respectively and appropriately placed in the Lovibond comparator. Calibrated colour disc was then inserted and rotated to match the colour.

Turbidity was measured by APHA 2130 B (Electrometric using Palintest Turbimeter Plus). The Palintest Turbimeter Plus operates according to ISO 7027 method for measurement of turbidity, utilizing two NIR light sources at 860nm as part of the QuadoptiX™ optical system. Calibration of the turbidity meter was conducted using Cal 1: 800NTU; followed by Cal 2: 100NTU; then Cal 3: 20NTU and; Cal 4: 0.02NTU standards.

Total Alkalinity was measured by APHA 2320 B (pH Titration) using 0.01mol dm^{-3} H₂SO₄, methyl orange and pH meter. At the endpoint titration colour changes from yellow to faint pink and the total alkalinity was computed using equation 1.

$$\frac{\text{mg}}{\text{l}} \text{Total alkalinity} = \frac{Ax1000}{\text{ml Sample}} \dots (1)$$

Where A = mL 0.01mol dm^{-3} H₂SO₄

Iron was measured by APHA 3500-Fe B (colorimetric) using Wagtech PTW10010 Potalab + (C) XA Photometer 7500 BT. Photometer was calibrated with blank water sample to be tested. The test was carried out by adding iron tablet (alkaline thioglycolate) to 10ml sample of water sample. The content was allowed to stand for 1minutes. The colour produced is directly proportional to the iron

concentration and measured using the photometer.

Escherichia coli and Total Coliforms were determined by APHA 9222 (Membrane filtration). The number of indicator organisms of microbial pathogens (*Escherichia Coli* and Total Coliforms) in the water samples were aseptically appropriately determined by filtering 100ml of each sample through membrane filter, inoculated and incubated at 44.5°C and 37°C for *Escherichia coli* and total coliforms respectively. Plates which had characteristic colonies after 24hours incubation in each case were selected. Colonies were counted and the results expressed in term of colony forming unit present in 100mL (cfu/100mL) of water sample. The *Escherichia coli* and total coliforms content was calculated using equation 2.

$$\text{cfu/100ml} = \frac{Ax100}{\text{ml sample filtered}} \dots (2)$$

Where A = Number of colonies counted

RESULTS AND DISCUSSION

Assessment of drinking water quality in a given catchment may be conducted under a wide variety of conditions and at varying spatial scales and levels (Oliver et al, 2016). The safety and wholesomeness of water can only be known and guaranteed if it's properly tested. Comparison of results obtained with the standards for physical, chemical and microbiological characteristics of water developed by WHO and NSDWQ ascertains margin of safety. The BSF efficiency assessment through system operation and water quality testing using various water sources represents one of the various scientific approaches towards unraveling safe water supply in rural areas.

Treatment Efficiency Assessment

Table 1 – 3 shows results obtained for both the raw sources and their equivalent treated water. Table 4 – 6 shows type and pattern of the BSF effects on water quality parameters. Comparative analysis between the raw water and the treated water characteristics signifies that, parameters with particulate origin (i.e. colour, turbidity, *Escherichia coli* and total coliforms) are effectively mitigated or removed. Whilst parameters such pH, EC, TDS and total

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alkalinity were increased in concentration and their increase reduces with elution.

Pathogens from faecal origin were 100% removed by the BSF system, as indicated by 100% average removal of *Escherichia Coli*, for both the stream, hand dug well and borehole water sources. However, pathogens from environmental origin were also 100% removed except for stream and hand dug well water sources, whose removal was 97% and 98.21% respectively. Though the environmental pathogens were not 100% removed, but all their values were within the standard and guidelines recommended by NSDWQ and WHO. Furthermore they are also above confidence level.

Other particulate matters whose consequent effect is aesthetic and objectionable characteristic such as colour, turbidity and iron (note that iron will be in suspension due to oxidation from iron (II) to iron (III)) are efficiently mitigated by the BSF system for all the raw water sources. All the parameters were 100% mitigated for borehole water source. However, average mitigation for colour is 97.23% and 91.05% for the stream and hand dug well water sources respectively. Furthermore, the average mitigation for turbidity is 96.45% and 98.85% for the stream and hand dug well water sources respectively. Both the parameters values were within the standard and guidelines recommended by NSDWQ and WHO.

Other Effects of BSF System

The BSF was observed to increase the concentration of pH, EC, TDS and alkalinity among parameters investigated, but the percentage intensification reduces with number of elution as shown in table 4 – 6. Average values 6.19%, 11.31% and 11.58% for pH were observed for the stream, hand dug well and borehole water sources respectively. Whilst average values 68.71%, 43.64% and 70.41% for degree of mineralization (EC) were observed for the stream, hand dug well and borehole water sources respectively. Furthermore, average values 69.01%, 43.52%, and 52.15% for dissolution of mineral salts (TDS) were observed for the stream, hand dug well and borehole water sources respectively. Conversely, average values 71.69%, 40.22% and 52.15% for intensity of alkalization were observed for the stream, hand dug well and

borehole water sources respectively. Though the rise in concentration of these parameters, but all the parameters values were observed to be within the standard and guidelines recommended by NSDWQ and WHO. The intensifications of the parameters concentration might be considered as health benefits, especially for gastrointestinal patient among the teeming population.

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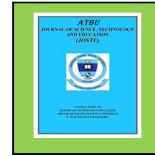


Table 1: Mando-Rigasa Stream Water Characteristics

DATE	RAW WATER									TREATED WATER									
	pH	EC (µS/cm)	TDS (mg/L)	Colour (TUC)	Turb. (NTU)	T. Alk. (mg/L)	Iron (mg/L)	E. coli (cfu/100ml)	T.C.	pH	EC (µS/cm)	TDS (mg/L)	Colour (TUC)	Turb. (NTU)	T. Alk. (mg/L)	Iron (mg/L)	E. Coli (cfu/100ml)	TC	
13/03/2023	7.2	79.8	39.7	146	50	211	0.05	21	148	7.7	174.4	87.2	5	2	440	0.00	0	5	
14/03/2023	7.4	91.1	45.4	120	41	260	0.06	17	156	7.9	160.9	80.7	4	2	455	0.00	0	8	
15/03/2023	7.2	100.2	50.0	101	34	269	0.06	69	250	7.6	144	71.7	2	1	430	0.00	0	4	
16/03/2023	7.3	87.6	44.0	125	42	272	0.07	70	257	7.7	119.1	59.5	3	1	390	0.00	0	5	
										NSDWQ	6.5-8.5	1,000	500	15	5	-	0.3	0	10
										WHO MPL	6.5-8.5	1,000	500	15	5	500	0.3	0	10

Table 2: Farin gida Hand dug Well Water Characteristics

DATE	RAW WATER									TREATED WATER									
	pH	EC (µS/cm)	TDS (mg/L)	Colour (TUC)	Turb. (NTU)	T. Alk. (mg/L)	Iron (mg/L)	E. coli (cfu/100ml)	T.C.	pH	EC (µS/cm)	TDS (mg/L)	Colour (TUC)	Turb. (NTU)	T. Alk. (mg/L)	Iron (mg/L)	E. Coli (cfu/100ml)	TC	
13/03/2023	6.6	153.2	96.7	20	7	280	0.02	67	250	7.8	254	126	3	0	455	0.00	0	3	
14/03/2023	6.9	151.5	75.8	45	16	300	0.03	68	260	7.8	231	116	5	0	465	0.00	0	6	
15/03/2023	7.1	155.2	77.5	193	65	354	0.07	80	258	7.7	213	106	8	3	438	0.00	0	5	
16/03/2023	7.2	205	99.6	90	31	392	0.05	22	231	7.6	244	119	5	0	456	0.00	0	4	
										NSDWQ	6.5-8.5	1,000	500	15	5	-	0.3	0	10
										WHO MPL	6.5-8.5	1,000	500	15	5	500	0.3	0	10

Table 3: National Water Resources Institute's Main Borehole Water Characteristics

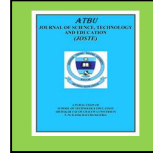
DATE	RAW WATER									TREATED WATER								
	pH	EC (µS/cm)	TDS (mg/L)	Colour (TUC)	Turb. (NTU)	T. Alk. (mg/L)	Iron (mg/L)	E. coli (cfu/100ml)	T.C.	pH	EC (µS/cm)	TDS (mg/L)	Colour (TUC)	Turb. (NTU)	T. Alk. (mg/L)	Iron (mg/L)	E. Coli (cfu/100ml)	TC
13/03/2023	6.7	120.8	60.5	6	2	223	0.02	0	8	7.8	245	122.6	0	0	433	0.00	0	0
14/03/2023	6.7	123.9	61.9	8	3	250	0.04	0	20	7.9	209	104.5	0	0	440	0.00	0	0
15/03/2023	7.1	118.9	59.5	3	1	245	0.03	0	21	7.7	188.3	94.6	0	0	400	0.00	0	0

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16/03/2023	7.2	125.5	62.7	3	1	296	0.05	0	25		7.7	190.5	95.1	0	0	400	0.00	0	0
										NSDWQ	6.5-8.5	1,000	500	15	5	-	0.3	0	10
										WHO MPL	6.5-8.5	1,000	500	15	5	500	0.3	0	10

Where:

NSDWQ = Nigerian Standard for Drinking Water Quality (NIS-554-2015); WHO MPL = World Health Organization Maximum Permissible Level (2012);
 EC = Electrical Conductivity; TDS = Total Dissolved Solids; Turb. = Turbidity; T. Alk. = Total Alkalinity; *E. coli* = *Escherichia coli* and; T.C. = Total coliform.

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Table 4: BSF Treatment Performance for Mando-Rigasa Stream Water

	TREATED WATER								
	pH % Inc.	EC % Inc.	TDS % Inc.	T. Alk. % Inc.	Colour % Dec	Turb. % Dec	Iron % Dec	E. Coli % Dec	TC % Dec
	6.94	118.55	119.67	108.53	96.6	96	100	100	96.6
	6.76	76.62	77.75	75	96.7	95.1	100	100	94.9
	5.56	43.71	43.4	59.85	98	97.1	100	100	98.4
	5.48	35.96	35.23	43.38	97.6	97.6	100	100	98.1
Average	6.19	68.71	69.01	71.69	97.23	96.45	100	100	97

Table 5: BSF Treatment Performance for Farin gida Hand dug well Water

	TREATED WATER								
	pH % Inc.	EC % Inc.	TDS % Inc.	T. Alk. % Inc.	Colour % Dec	Turb. % Dec	Iron % Dec	E. Coli % Dec	TC % Dec
	18.18	65.80	64.28	62.5	85	100	100	100	98.80
	13.04	52.48	53.53	58.33	88.89	100	100	100	97.69
	8.45	37.24	36.77	23.73	95.85	95.38	100	100	98.06
	5.56	19.02	19.48	16.33	94.44	100	100	100	98.27
Average	11.31	43.64	43.52	40.22	91.05	98.85	100	100	98.21

Table 6: BSF Treatment Performance for National Water Resources Institute's Main Borehole Water

	TREATED WATER								
	pH % Inc.	EC % Inc.	TDS % Inc.	T. Alk. % Inc.	Colour % Dec.	Turb. % Dec	Iron % Dec	E. Coli % Dec	TC % Dec
	16.42	102.81	102.64	94.17	100	100	100	100	100
	14.49	68.68	69.46	76	100	100	100	100	100
	8.45	58.37	58.99	3.27	100	100	100	100	100
	6.94	51.79	51.67	35.14	100	100	100	100	100
Average	11.58	70.41	70.69	52.15	100	100	100	100	100

Where:

EC = Electrical Conductivity; TDS = Total Dissolved Solids; Turb. = Turbidity; T. Alk. = Total Alkalinity; E. coli = *Escherichia coli* and; T.C. = Total coliform; Inc, = Increase and; Dec = Decrease.

CONCLUSION

Comparative analysis between the raw water and the treated water characteristics signifies that, parameters with particulate origin (i.e. colour, turbidity, *Escherichia coli* and total coliforms) were effectively mitigated or removed. Whilst parameters such as pH, EC, TDS and total alkalinity among parameters investigated increases, but the percentage intensification reduces with number of elution.. These rises of the parameters concentration might be considered as health benefits, especially for gastrointestinal patient among the teaming population. Hence, BSF might considered as a viable alternative for safe water supply option and enhancing access to safely

managed water for both rural remote, rural on-road and rural mixed context in Nigeria.

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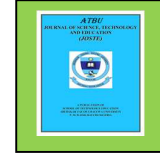
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