LAUTECH Journal of Engineering and Technology 12(1) 2018: 43-52

PILOT STUDY ON LOW COST DOMESTIC SLOW SAND FILTER FOR GROUNDWATER QUALITY IMPROVEMENT

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ABSTRACT

Most waterborne diseases can be prevented using simple, low cost water filtration techniques. The aim of this study is to design a low cost domestic slow sand filter, which can be operated and maintained effectiveness at household level by a member of the family, and determine its effectiveness in removing selected contaminants from the raw groundwater. Fine sand, activated charcoal, coarse sand, and gravel were used as media column for the developed slow sand filtration media. Common selected physico-chemical and microbial water parameters were examined before and after filtration with the slow sand filtration system. The filter was able to remove turbidity of the raw groundwater in the range of 86 - 92% without hampering the pH value or the temperature below the acceptable standards set by the Nigerian standards for drinking water quality. The filter media was able to reduce an average of 44 - 82%, 29 - 53% and 60 – 66% of total hardness, calcium hardness and chloride content, respectively from the chemical composition of the groundwater samples. The media also showed high effectiveness in reducing biological impurities from the groundwater. It was able to remove effectively the concentration of E-Coli and coliform counts. The average percent removal of E-coli and coliforms was found to be 100%. These were achieved with the aid of the bio-film layer that developed on the topmost part (fine sand layer) of the filter which was able to predate on the microbes in the groundwater samples. Slow sand filters are a sustainable means of water treatment when applied to appropriate source waters and when designed and operated properly.

Keywords: Slow sand filter, Water treatment, Water filter, Groundwater quality, Contaminants

INTRODUCTION

Outbreak of waterborne diseases transmitted by drinking or using contaminated or polluted water is a major challenge in most developing countries because of their capacity to result in simultaneous infection of a large number of people in the community affected. Most of these waterborne diseases can be prevented using simple water treatment techniques. Impact of such outbreak can be disastrous in rural communities with lack of adequate curative techniques and facilities to tackle the problem effectively and immediately. Those at greatest risk of waterborne disease are infants, young children, people who are debilitated and the elderly, especially when living in unsanitary environment.

In most developing countries, domestic water is derived from various available sources, such as private wells and rainwater (Olaoye and Olaniyan, 2012). The prominent sources of water in Nigeria include rain, surface water (rivers, streams, lakes, and springs), and underground water (wells and boreholes). Surface water has been found to require more treatments than those from other sources in the country (Ojoawo *et al.,* 2009; Ojoawo and Ogunrombi, 2014). Appropriate efforts are needed to ensure safe collection, treatment and perhaps storage of the drinking-water. Households and individuals water treatment is significant to increase confidence in its safety especially where community supplies are known to be contaminated or causing waterborne disease.

Outbreak of waterborne diseases such as typhoid, diarrheal disease, hepatitis A, cholera and dysentery can be prevented if adequate water treatment technique is put in place. The World Health Organization (WHO) estimates that 94 percent of diarrheal cases are preventable through modifications to the environment, including access to safe drinking water. Simple techniques for treating water at home, with the aid of filters, could save a huge number of lives each year (Das, 2014) as well as improve sanitation, hygiene and improve water supply.

Amidst various water purification techniques, water filter can be used to solve water quality problems associated with contamination, particularly in rural communities that depend greatly on surface or groundwater for drinking. Such water sources (rivers, lakes, well) and systems are often unprotected, hence, contain a lot of pollutants and pathogenic organisms which make them unfit for consumption. It is often reported that public and private water systems with unprotected surface or ground water sources are required to utilize a combination of filtration and disinfection to remove and inactivate disease-causing microorganisms (Selecky *et al.*, 2003).

Slow sand filtration is a technology that has been used for potable water filtration for hundreds of years. It is a process well-suited for small household and rural communities since it does not require a high degree of operator skill or attention. As its name implies, slow sand filtration is used to filter water at very slow rates. The typical filtration rate of 0.05 to 0.10 gpm/ft^2 is at least fifty times slower than rapid rate filtration. Slow sand is a relatively simple filtration process. No chemical addition is required for proper filtration operation. Particle removal is accomplished primarily through biological processes that provides the treatment. The biological activity is located primarily in the top surface of the filter while biological processes throughout the depth of the filter bed also influence particle removal. Slow sand filters are not backwashed like rapid rate filters, but are instead scraped or harrowed periodically when headloss increases (reaches 3 - 4 feet, depending on media size) across the filter bed. Typically slow sand filters must be scraped or harrowed every 1 - 12 months depending on water quality. During scraping, the top 1/8 – 1/2 inch of sand is removed from the filter bed. Eventually, after years of operation, the sand layer must be replaced to restore the depth of the filter bed. In some cases, filters are harrowed to break up the top layer of material and reduce headloss through the filter. (Selecky *et al*., 2003)

Slow sand filters have been an effective means of treating water for control of microbiological contaminants by building up a layer of filtered contaminants on the surface, which becomes the active filtering medium. The process is passive and the filter's effectiveness is dependent mostly upon the development of a biofilm attached to the sand grains and the schmutzdecke, a biologically active mat that develops on the filter surface. Inclusion of a layer of granular-activated carbon in a slow sand filter bed has improved capability for control of synthetic organic chemicals (Logsdon *et al*., 2002). Granular organic carbon may also be used with slow sand to treat a portion of the dissolved organics or colour.

Water, admitted to a slow sand filter, properly *"conditioned",* flows downward through the media. The filtration involves a number of interrelated removal mechanisms within the filter media. The removal mechanisms include the following processes: Sedimentation on media (sieve effect); Adsorption; Absorption; Biological action; and Straining (EPA, 1995).

The slow sand filtration media has better advantaged to the rapid sand because it is reliable, suitable for raw water that is low in turbidity and organic matter, cost-effective, and require less operator skill and time commitment to operate correctly than typical rapid rate filters (Selecky *et al*., 2003). Advantages and disadvantages of the two filtration method is highlighted in Table 1. The whole thickness of the media is utilized in the filtration process as opposed to the top layers of conventional rapid sand filters.

Conventional package slow sand treatment filters are available but are not commonly used because they are usually expensive and unaffordable by most household users. Sustainable filters should be developed to be effective, economical and user friendly. Recent studies have reported the efficiency of slow sand filters. Shishaye (2017) reported remarkable results in removing turbidity and coliform concentrations in water by a developed household-scale horizontal slow sand filter with an average 100% removal of coliforms. Souza *et al*., (2017) also confirm the effectiveness of slow sand filters in removing turbidity and colour. Lin *et al*., (2013) discussed the post-sedimentation application of poly-aluminum chloride in enhancing dual media filter performance and confirmed that the filter enhanced particle removal efficiency in dual media filtration. Feng *et al*., (2012) also reported that the performance of ammonium removal pathways and microbial community in granulated activated carbon-sand dual media filter was effective in drinking water treatment. Water quality studies through the use of slow sand filter by Osterdahl (2015) reported that most filters can decrease the levels of turbidity, colour, phosphate, total coliform and *E.coli* but not all parameters are decreased below the maximum acceptable value for the filters investigated in the study. Hence, the aim of this study is to design a low cost domestic slow sand filter which can be operated and maintained effectiveness at household level by a member of the family and determine its effectiveness in removing selected contaminants from the raw groundwater.

Table 1: Advantages and Disadvantages of Filtration Processes

Process	Advantages	Disadvantages
Rapid filtration	• Treats broad range of water quality • Removes color and dissolved organics	• Requires high level of operator skill and attention • Requires chemical addition for effective filtration • Sensitive to rapid changes in water quality • Higher operations cost
Slow filtration	• Lower level of operator skill required • Lower operations and maintenance cost • Very effective removal of bacteria, virus, protozoa, turbidity and heavy metals from the raw water • No need of electricity • Local materials can be used for construction • High reliability and easy to install in urban and remote areas • No need of chemicals • Long lifespan (estimated >10 years)	• Feasible only on high quality (low turbidity) water sources • Slow filtration rate • cleaning of the filter has to be done when clogged

Source: Selecky *et al*., (2003)

METHODOLOGY

Materials and Experimental Set- up

Locally available materials were used for the filter. The materials used include ; two polyethylene or plastic tank with lid, PVC pipe, fine and coarse sand, two grades of gravel, 1/2 inch and ¾ inch (washed 12 mm [½”] gravel and washed 6 mm [¼”] gravel), granular activated carbon, diffuser/ shower cans, tape rule. To select the type of filter media for the water treatment, the raw water quality was evaluated over a period of time. In this study, water media selection was based on the water quality listed in Table 2. The slow sand filter was selected based on result from raw water quality. The filter was designed with columns or layers of graded fine / coarse sand, activated carbon and graded gravel. The model of the slow sand filter is as shown in Figure 1.

Table 2: Raw Water Quality Limitation for Filtration Selection

	Filtration technology		
Parameter	Rapid sand	Slow sand	Membrane
Average turbidity	< 50 NTU	< 5 NTU	< 100 NTU
Maximum turbidity	< 100 NTU	< 10 NTU	< 200 NTU
Colour	< 75 SCU	< 10 SCU	< 10 SCU

Notes: NTU = Nephelometric Turbidity Units SCU = Standard Color Units
Source: Selecky *et al*., (2003)

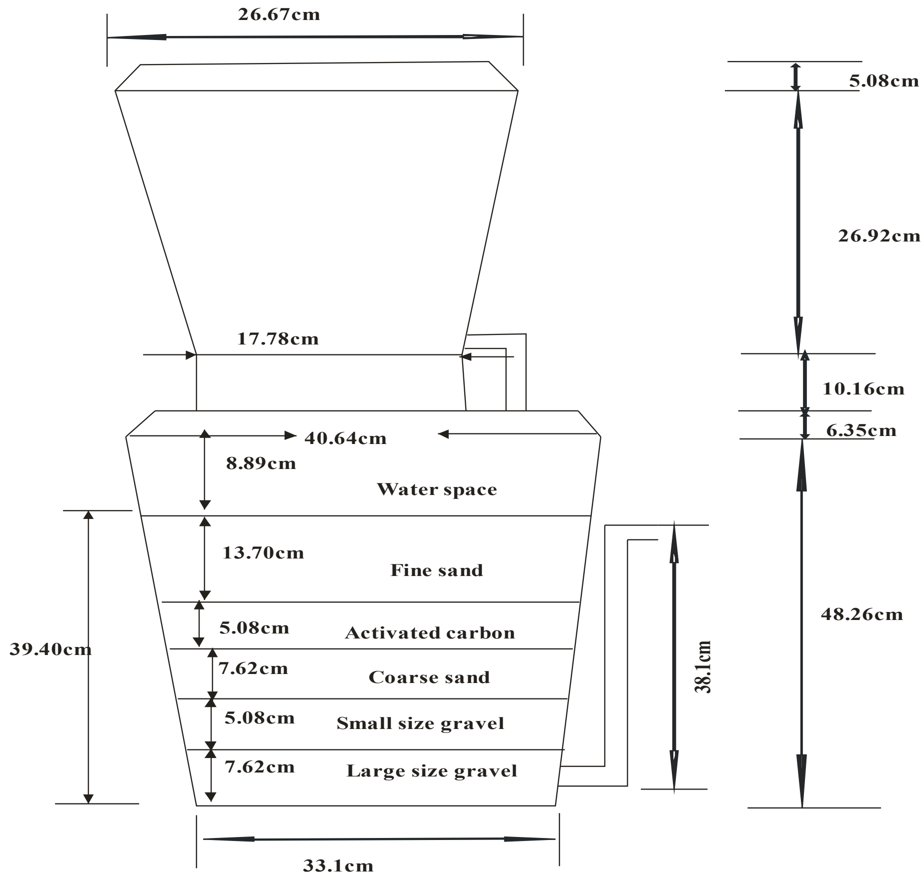

Figure 1: The 2-D view model of the filter

Filter compartments

The main components of the system are:

i. ***Raw water storage tank:*** This is the plastic tank with lid selected for the collection or storage of the raw water to be treated. The tank material is watertight. It was supported on a wooden material placed on the lid of the media bucket which raises the height of the bucket to allow for the inlet pipe to be fixed and it also support the weight of the plastic tank. The main function of the tightly fitted lid is to prevents contamination and unwanted pests into the water tank.The raw water tank was connected to link the sand/gravel media through the inlet pipe and valve.

ii. ***Sand and gravel filter media tank:*** This is the second plastic watertight container which housed the materials used in the filteration of the raw water. It comprises of fine sand, granular activated charcoal (granular organic carbon was used with the slow sand to treat a portion of the dissolved organics or colour), coarse sand, ½ inch gravel and ¾ inch gravel arranged in that order. The gravel and sand were thoroughly washed prior to installation in the filter column. Sieve analysis was perform in order to determine the sand gradation to be used in the media as outlined in Table 3. In performing the sieve analysis, the material retained on 12 mm and 6 mm sieves was used. Separate column was adopted for each of the sand gradation.

A perforated pipe was fixed at the inner base of the sand/gravel media which was connected to the outlet pipe and valve. The filter sand and gravels used were:

a. Thoroughly washed prior to installation in the filter column (free from dirt and other impurities)

b. Uniform in nature and size

c.. Hard and resistant to water and structures acting on it

Table 3: Sand Gradation Criteria

Parameter	Recommended Value
Effective Diameter (d_{10})	0.15 – 0.30/0.40 mm
Uniformity Coefficient (d_{60}/ d_{10})	< 2.5
% Passing #200 sieve unwashed	< 3%
% Passing #200 sieve washed	< 0.1%

Source : Selecky *et al*., (2003)

iii. ***Outlet pipe and valve:*** This was made of polyvinyl chloride (PVC) pipe material which was connected to the base of the sand/gravel media. It serves as passage for the filtered water (out of the media into a collection tank). It consists of valve for controlling the opening and closing of the pipe.

Installation

Two plastic containers or tank of different cross-sectional area was used to serve as the raw water storage and the bigger to serve as the filter media tank to house the filter materials for filtration. The lids for each of the plastic containers were tightly fitted to prevent further contamination and at the same time permit easy removal for maintenance. Two shower cans Plate 1(a) was attached to the inner part of the lid of the media tank to permit gentle dispense of water onto the filter media, filled with different grades of sand and gravel. The shower cans also served as diffuser plates which prevent the disturbance of the bio-film layer or top layer of the sand media which is responsible for the removal of pathogens and suspended solids by slowing down the flow rate of water passing into the sand column. A perforated PVC tube Plate 1(b) was passed into the last layer of the media tank (at the column for the ¾ inches gravel to allow the passage of the already filtered water out of the media tank. An extension of the perforated PVC runs out of the media tank which was designed to run above the height of the top sand layer to maintain the water level above the moist layer of the column. The filtered water passes out of the filter media through this pipe.

Diffuser plate

(a)

PVC pipe from raw water tank

(a)

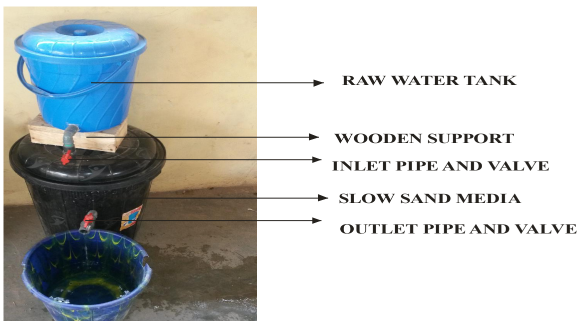

Plate 1: (a) Diffuser plates attached to the inner lid of the filter media (b) Perforated PVC pipe inside the filter media (c) Media tank showing outlet pipe and valve (d) complete filter set up

The first column from the top of the filter is an important part of the media; it contained the fine sand with a height of about ≈14 cm, then the granular activated carbon column (≈5.1 cm) followed by the coarse sand (≈8 cm). The formation of gelatinous layer (or biofilm) called the hypogeal layer or Schmutzdecke in the top layer is essential for microbiological contaminants removal.

Granulated activated carbon was used to adsorb natural organic compounds, taste and odor compounds, as well as synthetic organic chemicals in the raw water sample. Adsorbtion is both the physical and chemical process of accumulating a substance at the interface between liq (d) d solids phases. Activated carbon is an eff dsorbent because its a highly porous material which provides a large surface area to which contaminants can be adsorb. Below the course sand is the ½ inches gravel (≈ 5.1 cm) and the last column with the ¾ inches gravel (≈ 8 cm), these layers further act as filtration media for the water purification (Plate 2 a-e). Raw water sample was collected into the water tank and allowed to flow through the difussers onto the media through the top sand layer. The well water was introduced in from the top of the system, the water then passed through the layers of sand and purified. The filtered and purified water was collected at the bottom of the system through an outlet unit with a valve.

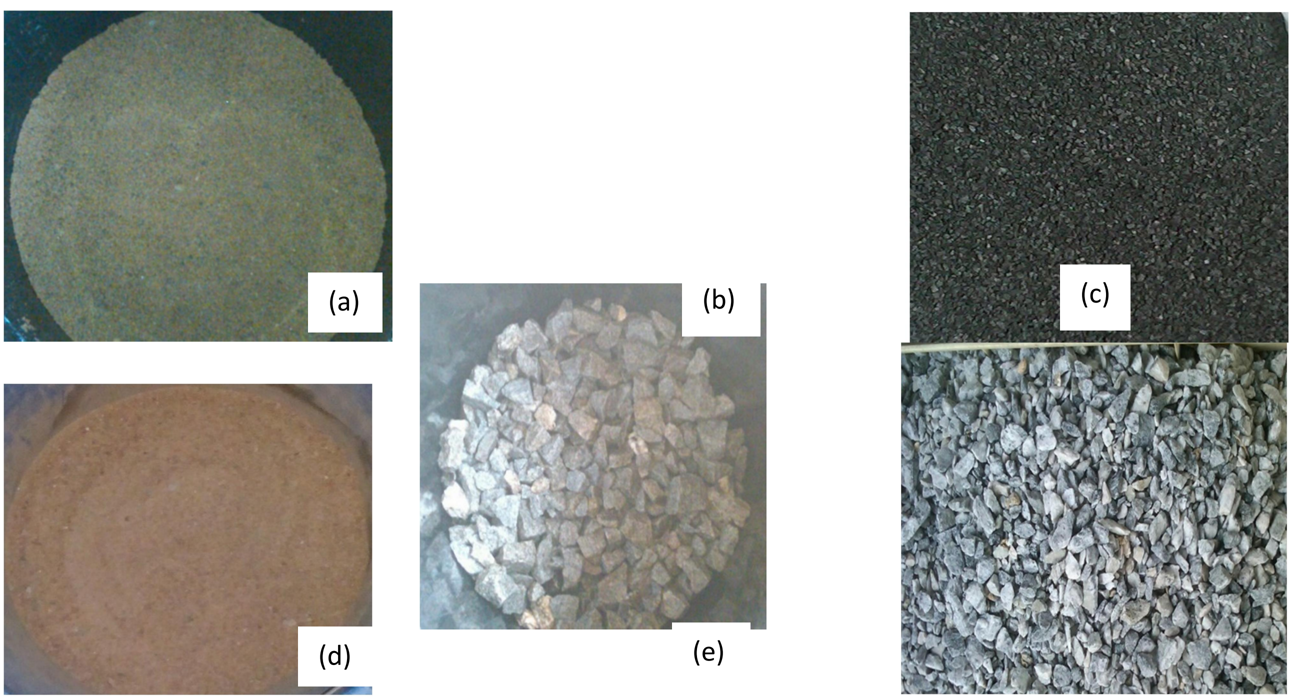

Plate 2: (a)Fine sand (b) Granulated activated carbon (c) Course sand (d) ½" gravel (e)3/4 " gravel

Water Sampling

Three shallow wells were selected for raw water samples collection denoted as W1, W2 and W3. They were selected based on proximity to various anthropogenic activities yet serves as main source of drinking water for the communities. Raw groundwater samples were collected in triplicate into sterilized plastic bottles and labelled accordingly (location and well No.). The raw samples were tested for physico-chemical and bacteriological composition in line with standard procedures.

The analysis of the water samples were carried out at the Water Resources Laboratory of River Niger Basin, Ilorin, Kwara State. Parameters tested were pH, temperature, turbidity, total hardness, calcium hardness, chloride, iron, zinc, coliform index, and *E-Coli*, using American Public Health Association (APHA) standard methods.
The pH was determined using the pH meter, temperature with thermometer, turbidity with turbidity meter
Total and calcium hardness were determined using EDTA titrimetric method while chloride (Cl^-) was determined using Argentometric titration. Multiple tube technique was used to estimate the number of coli form bacteria and *e-coli* present in the groundwater samples. Coliform bacteria are grain negative, non-sparing, facultative anaerobic bacillus contamination through faecal deposits

RESULT AND DISCUSSION

Raw and Filtered Groundwater Composition

Analysis of selected parameters from the groundwater samples before and after going through the process of filtration is given in Table 3. Most of the parameters were noted to have drastically reduced values after the filtration process and therefore fall within the stipulated limit by WHO. The specific observations on some of the selected parameters are discussed as follows:

Turbidity

The average value for turbidity measured varied from 3 - 6 NTU, while the recommended permissible limit in drinking water should be < 5 NTU. Samples from W1 and W3 are within the recommended limit while samples obtained from W2 was higher than the threshold. Turbidity, typically expressed as nephelometric turbidity units (NTU), describes the cloudiness of water caused by suspended particles (clay and silts), chemical precipitates (e.g. manganese and iron), organic particles (plant debris) and organisms. Turbidity is often caused by poor source water quality. High turbidity can give the water a cloudy or muddy appearance and can lessen the effectiveness of disinfection, lead to staining of materials, fittings and clothes. High levels of turbidity can also protect microorganisms from the effects of disinfection, stimulate the growth of bacteria and give rise to a significant chlorine demand (WHO, 2017). However, after filtration the turbidity values of all the samples was less than 1.0 NTU. Percentage removal for turbidity ranged from 86.25 – 91.27%. By implication, filtered samples produce water with no visible turbidity. It is essential that an overall management strategy be implemented through filtration as well as protection of source water from further contamination.

The pH value

Average pH value was 6.8, 6.7 and 6.5 for raw water samples from W1, W2 and W3 respectively and 6.5, 6.6 and 6.5 for the filtered samples respectively. These pH values indicate that water samples before and after filtration was slightly acidic and within the recommended limits. pH is a measure of the acidic or alkaline nature of the water. pH is controlled to minimize corrosion in pipes and fittings. The pH value of 6.5 to 8.5 is often suggested, and up to 9.2 for areas where cement mortar-lined pipes are present, provided there is no deterioration in microbiological quality. Although pH usually has no direct impact on consumers, it is one of the most important operational water quality parameters. Hence, careful attention to pH control is necessary after filtration.

Temperature

Water samples from both the raw and filtered samples shows little or no variation in temperature (26.0 ºC, 25.5 ºC and 27.0 ºC for raw water samples and 26.5 ºC, 26.0 ºC and 27.0 ºC for filtered samples obtained from W1, W2 and W3 respectively. It can be deduced that the filter media did not alter the temperature of the water samples, hence the slow sand filter used do not alter the temperature of the water.

Total hardness and calcium hardness

The average total hardness obtained for all the water samples was less than 200 mg/l. Those from W2 and W3 was less than 100 mg/l indicative of water softness (hardness < 100 mg/l). There was considerable reduction in hardness from 167.15 to 31.5 mg/l, 63.43 – 33.47 mg/l and 68.26 – 38.25 mg/l for samples obtained from W1, W2 and W3 respectively. About 44 – 82% reduction in total hardness was achieved after filtration. Hardness is usually not of great health concern at levels found in drinking-water, though it often affect acceptability of drinking water if level is high (degree of acceptability of water hardness may vary for each individual). Hardness caused by calcium and magnesium is usually indicated by precipitation of soap scum and the need for excess use of soap to achieve cleaning. Similarly, results revealed percentage reduction of calcium hardness of 53.33, 30.50 and 28.7% for W1, W2 and W3 respectively. The taste threshold for calcium ion is in the range of 100 – 300 mg/l with extreme values at 500 mg/l (WHO, 2017).

Chloride

Chloride concentration was low in all the samples tested. Concentration in raw water samples ranged from 32 -35 mg/l. After the filtration process chloride concentration was reduced to a range of 12 -14 mg/l. Percentage removal was 65.79, 59.86 and 60.41 % for W1, W2 and W3 respectively. Chloride is usually not of health concern at levels found in drinking-water. However, high concentrations of chloride give a salty taste to water and may affect the acceptability of the drinking water. Taste thresholds is in the range of 200 – 300 mg/l.

Iron

The concentration of iron in the raw and filtered treated water samples was less than 0.3 mg/l. The ADWG, 2003 suggests a limit of 0.3 mg/l for iron in water while other standard limit it to 0.1 mg/l. There is usually no noticeable taste of iron at concentrations below 0.3 mg/l, although turbidity and colour may develop. No health-based guideline value is proposed for iron (WHO, 2017). Iron can occur naturally in water, due to the presence of soil particulate matter. High concentrations of iron can impact colour to water and reduce acceptability of the drinking water as well as cause staining problems. Water samples before and after filtration were within the acceptable limit of 0.3 mg/l for iron.

Zinc

Zinc imparts an undesirable astringent taste to water at a taste threshold concentration of about 4 mg/l (as zinc sulfate). The average concentration of zinc in all the samples tested was within the threshold with concentration levels less than 0.05 mg/l. Concentration of zinc reported from most surface water do not exceed 0.01 mg/l while for groundwater samples, zinc concentrations do not exceed 0.05 mg/l (WHO,2017). Water containing zinc at concentrations in excess of 3–5 mg/l may appear opalescent and develop a greasy film on boiling.

Bacteriological analysis

Escherichia coli (*E-coli*) or coliforms were analyzed to verify the presence of pathogenic organisms in water. *Escherichia coli* provides conclusive evidence of recent faecal pollution which should not be present in drinking water. Coliform bacteria was present in all the samples tested in the range of 5-23 CFU. About 100% reduction in coliform removal was achieved in all samples tested. Drinking water standards specified that coliform must not be detectable in any 100 ml water sample. *E. coli* was present in all samples taken from W1 and W2, but absent in samples obtained from W3. Similarly about 100% *e-coli* removal was achieved in all the samples tested. *E-coli* is found in large numbers in the faeces of humans and other warm-blooded animals, only a few strains are hazardous to human health. Results revealed that all samples were free from pathogenic organisms after filtration except samples from W1. Tests results show that the media is very effective for the removal of biological contaminations. Biological activity at the top of the layer is the main mechanism that helped in contaminant removal in the water. A bio-film layer or schmutzdecke which develops at the top of the filter media contains microbial community which is responsible for removal of pathogens in the water sample.

The e-coli is removed through a combination of both physical and biological process. In the physical process, the bacterial become mechanically trapped in the spaces between the sand grains, and biological process takes place in the bio-film layer that developed on the top of the filter. Absorption also facilitates the removal of *e-coli* as it can become attached to each other or the bacteria may die because of food scarcity and oxygen depletion.

Table 3: Raw and Filtered Water Characterization

	Raw water samples			Filtered water samples			WHO Limit
Samples	W1	W2	W3	W1	W2	W3	
pH	6.8	6.7	6.5	6.5	6.6	6.5	6.5 – 8.5
Turbidity (NTU)	3	6	4	0.25	0.7	0.55	5
Tempt. (^{0}C)	25	25.5	24.7	26.5	26	27	
Total Hardness (mg/l)	167.15	63.43	68.26	31.5	33.47	38.26	100-300
Ca^+ Hardness	85.5	35.25	33.25	39.9	24.5	23.7	
Chloride(mg/l)	35.08	34.38	32.33	12	13.8	12.8	200
Iron(mg/l)	0.25	0.24	0.26	0.25	0.23	0.26	0.1
Zinc(mg/l)	0	0.04	0.05	0	0.03	0.03	5.0
Coliform (cfu/100 ml)	21	23	5	2	0	0	0
***E- coli* (cfu/100 ml)**	Present	Present	Absent	Absent	Absent	Absent	0

iv. CONCLUSION AND RECOMMENDATION

The filter was able to remove turbidity of the raw groundwater in the range of 86 -92 % without hampering the pH value or the temperature below the acceptable standards set by the Nigerian standards for drinking water quality. The filter media was able to reduce an average of 44 - 82%, 29 - 53% and 60 – 66% of total hardness, calcium hardness and chloride content respectively from the chemical composition of the groundwater samples. The media also showed high effectiveness in reducing biological impurities from groundwater, it was able to remove effectively the content of *E-Coli* and as well reduce coliform counts to a minimum level with the aid of the bio-film layer that developed on the topmost part of the filter that contains pathogens which are able to predate on the microbes in the groundwater samples.

The study shows that purification of groundwater using the process of slow sand filtration is feasible. The outcome of the filtration produced satisfied quality water standards which offers a satisfaction for consumers. However, because slow sand filters are prone to clogging, operational monitoring is required. Operational monitoring includes observing and testing parameters such as turbidity, *e-coli*, coliform and structural integrity of the tanks. The primary periodic maintenance activity for slow sand filtration is re-sanding. Regular backwashing of the filtration unit will equally go a long way in minimizing the organic bed load and thereby enhance potability of water. Each time a slow sand filter is scraped, some of the filter sand is removed. Filtration followed by disinfection (by one or a combination of disinfectants) is the most practical method and effective technique to remove or inactive protozoal cysts in drinking water.

REFERENCES

ADWG - Australian Drinking Water Guidelines (2003). Water quality tests, South East Water Limited

Das .P. (2014). Study on the performance of dual media filter for surface water treatment, Published MEng. Thesis, submitted to School of Water Resources Engineering, Faculty of Engineering and Technology, Jadavpur University, India

EPA (1995). Water treatment manuals, filtration, Published by the Environmental Protection Agency, Ireland

Feng. S., Xie. S., Zhang. X., Yang. Z., Ding. W., Liao. X., Liu. Y. and Chen. C. (2012). Ammonium removal pathways and microbial community in GAC sand dual media filter in drinking water treatment, *Journal of Environmental Sciences,* 24 (9) :1587-1593.

Lin. P.H., Lion. L.W., Weber-Shrink. M.L. and Bordlemay. C.L. (2013). Post sedimentation application of Poly-Aluminum Chloride to enhance dual media filter performance, *Journal of Environmental Engineering, 139* (5): 612-617.

Logsdon G. S., Roger .K., Solomon .A., and Shawn LaBonde (2002). Slow sand filtration for small water systems, *J. Environ. Eng. Sci.*, 1: 339–348

NSDWG (2007). Nigerian Standard for Drinking Water Quality. Plot 1687, Lome Street, Wuse Zone 7, Abuja Nigeria. SON Governing Council.

Ojoawo, S.O., Adedeji K.A and Kasali, S (2009). Effects of storage medium and time on quality of water in a temperate region. *International Journal of Civil Engineering*, Nigeria, 1 (1): 69-79. Blackwell Educational Books.

Ojoawo, S.O. and Ogunrombi, J.A. (2014). A pre-upgrading performance evaluation of Ogbomoso waterworks, Nigeria. *International Journal of Innovative Research in Engineering & Science*, 10 (3): 16 – 27.

Olaoye, R.A and Olaniyan, O.S (2012). Quality of Rainwater from different root material, *International Journal of Engineering and Technology*, (IJET, UK), 2, (8): 1413-1421

Osterdahl M. (2015). Slow sand filtration as a water treatment method: An inventorying study of slow sand filters purification rates in rural areas in Colombia, Published Bachelor of Science Thesis, in Environmental and Engineering, Karlstads Universitet 651 88 Karlstad

Selecky .M., White .B. and Grunenfelder .G. (2003). Guidance document : slow sand filtration and diatomaceous earth filtration for small water systems, Washington State Department of Health, Division of drinking water, (360) 236 – 3164

Shishaye H.A. (2017). Design and Evaluation of Household Horizontal Slow Sand Filter, *Current Journal of Applied Science and Technology*, 23 (1): 1-10,

Souza F.H., Guedes T. L., Burgardt .T. and. Sens M. L (2017). Upflow slow sand filtration: the interference of the support layer on filtration and filter cleaning, Leading Edge Conference on Water and Wastewater Technologies ,At: Florianópolis Ordinal: 14th, Affiliation of IWA

WHO (2017). Guidelines for drinking-water quality: fourth edition incorporating the first addendum, Geneva: World Health Organization; 2017. License: CC BY-NC-SA 3.0 IGO.