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IMPACT OF GRANULAR ACTIVATED CARBON AND MAGNETIC FIELD IN SLOW SAND FILTER ON WATER PURIFICATION FOR RURAL DWELLERS

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ABSTRACT

Most farmers that produce food crops in Nigeria live in rural areas where potable water is not available. The farmers in some areas have problem of water borne diseases which could affect their health and could lead to death. This study was conducted to determine the impact of incorporating Granular Activated Carbon (GAC) and Magnetic Field (MF) in Slow Sand Filter (SSF) on the purification of water for rural dwellers. The SSF was constructed using PVC pipe (152.4 mm diameter and 1100mm long) with layers of fine sand (size 0.25mm and 350mm depth), followed by GAC (10mm size and 100 mm depth), fine sand (0.25mm with 500mm depth) and gravel (grain size 10-14 mm and 100mm depth). The SSF was kept moist for 21 days for biofilm layer (*schmutzdecke)* to fully develop which is essential for trapping bacteria. Two SSFs fabricated consist of SSF+GAC+MF as Filter 1, SSF+GAC as Filter 2 and Control (Raw water without passing through the filter. Water samples were collected from the filter and analyzed. The discharge capacity of the filter was 25 litres/h. Total bacteria counts (TBC) for Filter 1 and Filter 2 and control were 2.4, 4.6 and 8.1 cfu/mg, respectively. Total coliform count for Filter 1 and Filter 2 and control were 1.7, 3.0 and 6.4 cfu/100mL, respectively. The filters reduced water hardness, turbidity, lead, copper, electrical conductivity and reduced TCC by 53.13-73.44% but increased pH from 5.8 to 7.1-7.3. The SSF is recommended for water purification in the rural area.

1.Introduction

Most rural dwellers especially the farmers that produce food crops in Nigeria live in rural areas and most of them don't have access to potable water. Yusuf and Murtala (2020) reported that rural dwellers depend mostly on surface water such as ponds, open wells, springs and streams for drinking water. Water from these sources are usually contaminated with disease-causing organism that could cause certain diseases to man. Hammer and Hammer (2012) reported that contaminated water from ponds and streams could be contaminated with toxic chemicals and pathogens which could cause water-borne diseases such as cholera and typhoid to man. Ashbolt (2004) also reported that lack of potable water and proper sanitation in rural areas is the main cause of gastrointestinal diseases in some developing countries in Africa. Ankidawa and Tope (2007) reported that water purification in the rural areas is difficult and expensive because of bad roads for transportation and lack of electricity for water treatment plant. Therefore, purification of water for farmers in the rural areas using simple and low-cost water treatment equipment is needed.

Slow sand filter is a simple equipment for purifying water which does not require electricity and is effective for removal of debris and disease-causing organism from the water (LeChevallier and Au, 2004; Yusuf *et al*., 2019). WHO (1996) indicated that SSF is effective in the removal of 98 to 99% of microorganism from water. El-Harbawi *et al*. (2010) stated that SSF could remove particles and some toxic chemicals from the water. The removal of contaminants from water by SSF and its purification efficiency depends on the filter media, the depth of the media especially the fine sand and the discharge of water during filtration (Abudi, 2011). Bagundol *et al*. (2013) reported that the depths of filter bed for fine sand with 60 and 90 cm could reduce the turbidity by 90% and remove E. Coli from the water.

EPA (2016) indicated that activated carbon is effective for the removal of some compounds that could cause taste, odour, colour and toxic to man by adsorption which the filter sand could not remove. Basha *et al*. (2023) reported that activated carbon from walnut shell and green leaves are good adsorbent agent and they are efficient in the removal of Lead and Arsenic. GAC is an adsorbent agent that has ability to remove physical, chemical and some organic compounds from the contaminated water while sand medium traps the pathogens from the water during the filtration. Activated carbon is commonly produced from agricultural materials such as wood, coconut shell and rice husk. Chandarin *et al*. (2023) reported that solid adsorbents are environmentally friendly materials for the removal polluants from the wastewater. Tobarameekul *et al*. (2022) reported that common adsorbent agents that could be used for water purification are zeolite, activated carbon and metal-organic frameworks.

The first step in production of activated carbon is carbonization of the agricultural material to obtain charcoal under anaerobic environment (without oxygen) at a temperature of 700 °C (Dileck and Oznuh, 2008). Das *et al*. (2015) reported that activated carbon is produced by heating charcoal in a furnace with temperatures ranging from 800 to 900 °C. Das *et al*. (2015) also stated that activated carbon could be prepared by using chemicals like KOH, NAOH, ZCl_2 and H_2SO_4.

Magnetic field could be used to enhance water purification, modify the molecular structure of water and energize the water. Magnetized water is produced by allowing water flow through magnetic field in a pipe and the water must flow vertically to the magnetic field according to Fleming's Right-hand rule (Chern, 2012). Kozic *et al*. (2006) reported that magnetic field could be used to purify water, reduce the water hardness, modify the water clusters and soften the water for human consumption and good health. Babu (2010) pointed out that magnetic field enhances water purification efficiency, modifies the water structure and reduces the surface tension which is more useful to both plant and animal. (LeChevallier *et. al*, 2004) stated that incorporating magnetic treatment unit in slow sand filter could reduce bacteria, algae, E. coli and scale formation in water. The objective of this study was to develop and determine the impact of incorporating GAC and MF treatment unit in SSF on water purification of some selected physical, chemical and bacteriological properties of water.

2. Materials and Methods

2.1. Preparation of fine sand for the slow sand filter

A 40 kg of fine sand was collected within Ilorin, the sand was sun dried for 2 days, then sieved through 0.25 mm and soaked in water for 2 days for softening and easy separation of any foreign particles from the sand. The sand was thoroughly washed with cleaned water to remove particles, soluble element sand then sun dried for another 4 days. Washing of the sand is essential to have a clean filter sand material that is free from organic matter, clay particles, insects and some soluble chemicals. Gravels were collected and sieved through 15 mm and 6 mm sieves; the gravels retained were thoroughly washed and used as the supporting layer. A perforated cover with 4 mm in diameter holes was put below the gravel through which the filtered water passes to the lower chamber.

2.2. Granular activated carbon for the filter

Granular activated carbon (GAC) was prepared using coconut shell which was burnt to have the charcoal. The charcoal was ground, sieved through 10 mm standard sieve, put in a crucible and then heated in a furnace at temperature of 700 ^{0}C for 2 hours. The GAC was washed with distilled water to reduce the pH level and then dried in an electric oven at 105 ^{0}C for 2 hours to have a dry granular activated carbon as shown in Figure 1.

Figure 1. Granular activated carbon for the filter

2.3. Magnetic treatment unit incorporated in the slow sand filter

Magnetic treatment unit incorporated in the filter was a rectagular pipe (15 mm by 60 mm and 600 mm long) constructed using a transparent perspex glass (2 mm thick). A total of 12 pieces of 50 × 25 × 10 mm neodymium magnet were arranged on the two sides of the rectangular pipe as shown in Figure 2. The rectangular plastic pipe was folded to form 3 layers to have a longer magnetic treatment unit with 12 pieces of magnet. The neodymium magnet covers a total length of 450 mm and it has magnetic flux density of 1.0Tesla (10,000 Gauss).

Figure 2. Pictorial view of neodymium magnet

2.4. Description of the slow sand filter

The SSF was constructed using locally available materials in Ilorin, Kwara State, Nigeria. The filter chamber was constructed from 6 inches (152.4 mm internal diameter) PVC pipe and 1100 mm long. A diffuser of 20 mm openings is placed at the inlet pipe to the filter chamber for even distribution of water over the filter medium. The drain pipe and other fittings were fitted to the base that serves as drain through which the water would be collected.

The gravel (grain size of 14 mm) was put at the bottom of the filter to 60 mm height and gravel of 10 mm grain size was also put after the 14 mm gravel to a height of 40 mm. The two layers of the gravel allow easy flow of filtered water after the fine sand medium. Water would flow from the raw water storage tank (40 litres capacity) through 12.7 mm PVC pipe to the filter chamber. Both the inflow and outflow pipes have control taps for regulating the inflow discharge of water from the water storage tank into the filter chamber and from the filter to the outlet when water is needed for drinking. The SSF has a discharge (capacity) of 25 litres/h.

The total cost of the SSF as at March, 2021 using the available materials in Ilorin was sixty-seven thousand (₦67,000) which is equivalent to 175.85 U.S. Dollar (USD175.85).The orthographic drawing of the SSF is shown in Figures 3 and 4. The order of arrangement of the media in the SSF from the top of the filter was granular activated carbon, fine sand, gravels. The description and the arrangements of the filter media from the top of the filter were as follows:

i. Supernatant with 50 mm depth (space above the filter bed)
ii. Fine sand of grain size 0.25 mm with a depth of 50 mm
iii. Granular activated carbon of 10 mm size with depth of 100 mm
iv. Fine sand of effective grain size 0.25 mm with filter depth of 500 mm
v. Gravel of grain sizes of 10 -14 mm of depth 100 mm

vi. Filtered water chamber of depth 350 mm.

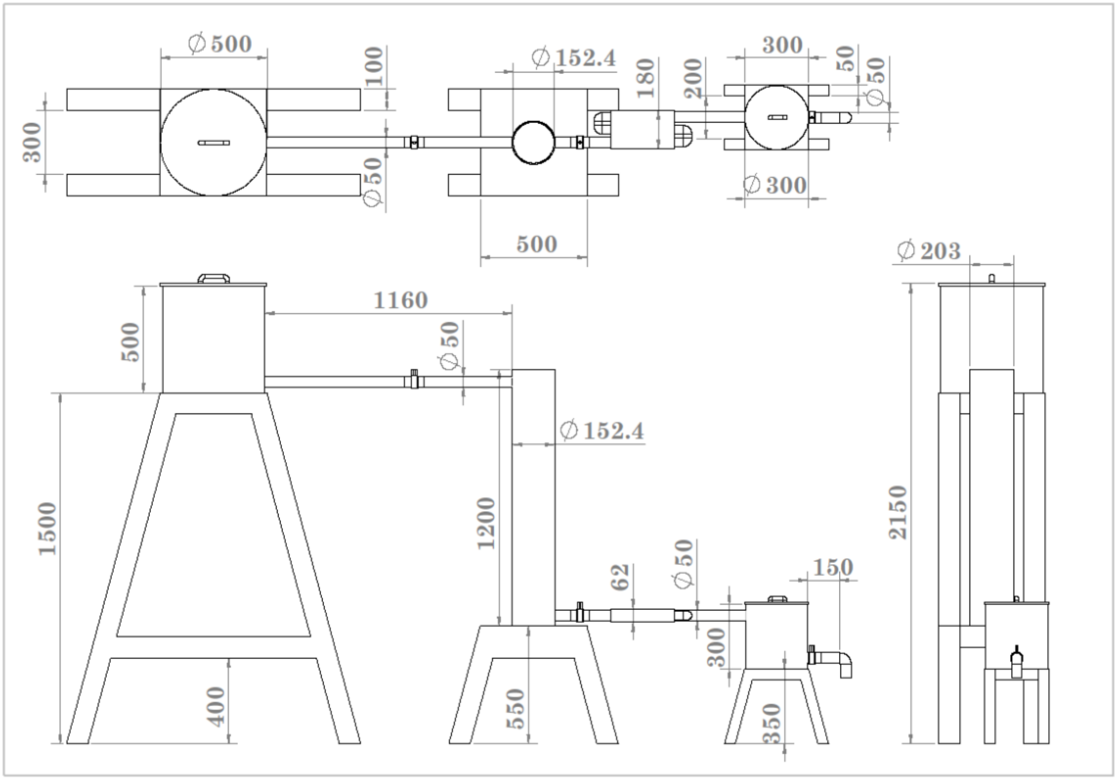

Figure 3. Orthographic drawing of the slow sand filter

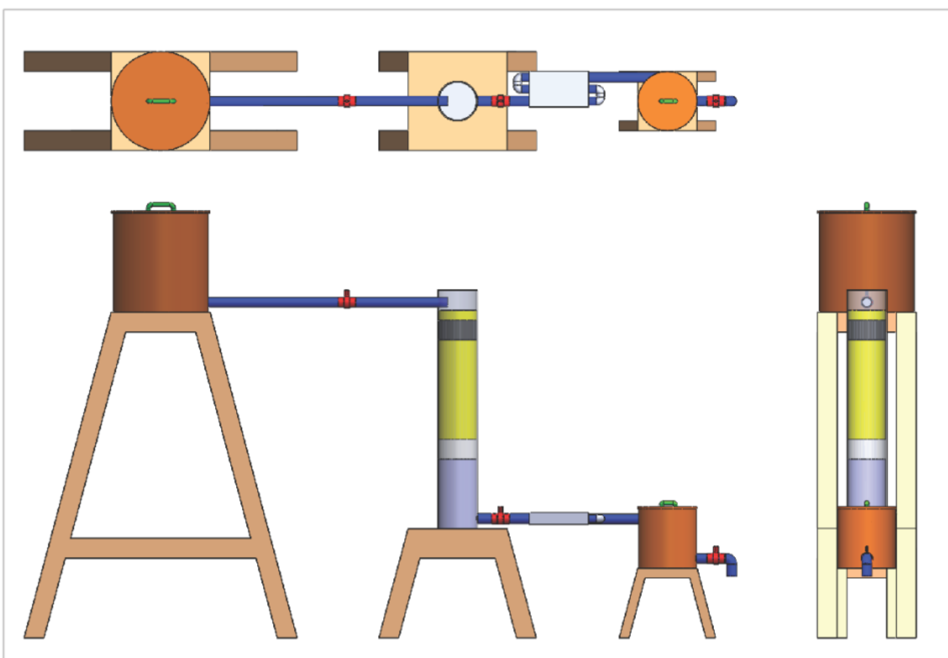

Figure 4. Orthographic view of the slow sand filter

2.5. Determination of flow discharge and water analysis of the filtered water

The discharge of the SSF was determined to know the quantity of water which the filter can produce per hour and water quality analysis was conducted to know if the filter is working satisfactorily. The discharge of the SSF evaluated by determining the volume of water it could filter per hour using Equation (1). The performance evaluation of the SSF on water purification was carried out using well water within the university campus at male hostel. Water samples were collected using sterilized 750 ml plastic bottle.

The physical, chemical and bacteriological properties analyzed in the water were Turbidity (appearance), pH, Electrical conductivity, Total hardness, Lead, Cadmium, Manganese, Copper, Calcium, Total bacteria counts, E. Coli and total coliform counts. The physicochemical and bacteriological properties of the water were determined using the standard methods (AOAC, 2000).

$$Q = \frac{V}{T} \qquad (1)$$

where Q is the discharge of the SSF (litre/h), V is the volume of water collected from the outlet (litre) and T is the time taken to obtain the volume of water (h).

2.6 Statistical analysis using paired t-test for the water purification of the slow sand filter

A paired t-test was used to check the effect of magnetic field and GAC incorporated in the SSF were significant or not on the purification of water. The mean, standard deviation, standard error and t-test values were computed using Equations (2), (3), (4) and (5), respectively as reported by Montgomery (1998). The data used for determining the Paired t-test is presented in Table 1 which was extracted from Table 2. The calculated values of t-test and that of table values of the t-test were compared at α = 5 % (α = 0.05).

$$\bar{x} = \frac{\sum x}{n} \quad (2)$$

$$\delta = \sqrt{\frac{\sum x^2 - n\bar{x}^2}{n-1}} \qquad (3)$$

$$\delta_{Er} = \frac{\delta}{\sqrt{n}} \quad (4)$$

$$t_{cal} = \frac{\bar{x}}{\delta_{Er}} \quad (5)$$

where $\overline{x}$ is the mean of difference of the data x_1 and x_2, Σx is the summation of x, n is the number of observations, δ is the standard deviation, δ_{Er} is the standard error and t_{cal} is the calculated value.

Table 1. Determination of the Paired t-test

x_0	x_2	$x = x_0 - x_2$	x^2
5.8	7,3	-1.5	2.25
3.35	3.24	0.11	0.0125
420	390	30	900
342	305	37	1369
32	24	8	64
80	40	40	1600
320	260	60	3600
1.20	1.04	0.16	0.0256
0.01	0.01	0.00	0.00
1.03	1.01	0.02	0.0004
0.05	0.06	-0.01	0.0001
0.00	0.01	-0.01	0.0001
9.03	9.01	0.02	0.0004
175.14	174.71	0.43	0.1849
6.90	5.90	1.00	1.00
3.24	2.80	0.44	0.1936
8.10	2.40	5.70	32.49
6.4	1.6	4.80	23.04
N = 18		**∑d= 186.16**	**∑ d^2= 7,592.1972**

x_0 = Raw water, x_1 = water parameters that filtered through filter 1 (SSF+GAC+MF)

$$\bar{x} = \frac{186.16}{18} = 10.342 \quad (2)$$

$$\delta = \sqrt{\frac{7{,}592.1972 - 18(10.342)^2}{18-1}} = 18.258 \quad (3)$$

$$\delta_{Er} = \frac{18.258}{18} = 4.303 \quad (4)$$

$$t_{cal} = \frac{10.342}{4.303} = 2.403 \quad (5)$$

Similarly, Raw water versus water parameters filtered through filter 2 (SSF + GA), t_{cal} was 2.340 but table value of t-test is 2.110 at 17 degree of freedom and at $\alpha \leq 0.05$.

3. Results and discussion

The fabricated SSF shown in Figure 5 has a discharge of 25 litres/h of clean drinkable water for people especially in rural areas where potable water are not available. The results of the performance evaluation of the slow sand filters 1 and 2 on the removal of cations mainly the heavy metals, anions, bacteriological properties and water hardness are shown in Figures 6, 7, 8 and 9, respectively. The total bacteria counts (TBC) for filter 1 (SSF + GAC + MF), filter 2 (SSF + GAC) and the raw water without passing through the filter (control) were 2.4, 4.6 and 8.1 cfu/mg, respectively while the total coliform counts (TCC) for Filter 1, filter 2 and control were 1.7, 3.0 and 6.4 cfu/100mL as shown in Table 2. The filter 2 with GAC only reduced the TBC by 43.21% but the filter 1 with GAC and MF reduced TBC by 70.37%. The filter 2 with GAC only also reduced TCC by 53.13% while slow sand filter 1 GAC and MF reduced TCC by 73.44% as presented in Table 2.

The result of this study is in agreement with the study of LeChevallier and Au (2004) which reported that slow sand filter could remove pathogens in the water to minimum value with the removal of total coliforms varied from 84.35 to 99.5% and faecal coliforms varied from 48.1 to 70.0%. WHO (1996) reported that SSF could remove microbial pathogens that can cause diseases to man in the rural and urban areas by 98 to 99 %. The percentage removal of TBC in this study was 43.21 to 70.37% compared to 84.35 to 99.5% which depends on the quality of the raw water, filtration rate, media sizes and depths of the media as reported by LeChevallier and Au (2004).

Magnetic field incorporated in the slow sand filter enhanced the removal of TBC and TCC and this agreed with the study of Nasher and Hussein (2008) that magnetic field is a simple physical method for eliminating bacteria from a system. Brkovic *et al*. (2014) also concluded that magnetic field reduced number of microbes in the oral cavity.

The filters reduced the water hardness, turbidity, lead, copper and electrical conductivity as shown in Table 2. The slow sand filter 1 reduced the TDS, Turbidity, Hardness and Sodium by 10.82, 3.28, 25.00 and 13.33%, respectively while the slow sand filter 2 also reduced the TDS, Turbidity, Hardness and Sodium by 9.36 and 3.28%, 25.00 and 13.33%, respectively. The two filters reduced the values of Electrical conductivity, BOD, COD, reduced concentrations of Copper, Nitrite, Nitrate, Phosphorus and Sulphate after filtration. The results of the filtration in this study agreed with the findings of Bagundol *et al*. (2013) that SSF could reduce turbidity by 90% which depends on the depths of filter bed (fine sand). This study was also in agreement with the study of Chatterjee (2007), Hammer and Hammer (2012) that SSF improved the physical and chemical properties of water.

The effect of the filtration of water through filter 1 and filter 2 were significant on the purification of the water with values of t-test of 2.403 and 2.340 compared to the table value of t-test of 2.110 at $\alpha \leq 0.05$ as presented in Table 3. All the properties of raw water and water after filtration were within the permissible limits of SON (2007) and WHO (2008).

Figure 5. Pictorial view of the fabricated slow sand filters

Table 2. Properties of water before and after filtration

Water properties	Filter 1	Filter 2	Raw water	SON 2007	WHO 2008
pH	7,3	7.1	5.8	6.5-8.5	6.5-8.5
Turbidity (NTU)	3.24	3.24	3.35	5.00	5.00
EC (μS/cm)	390	400	420	1000	1000
TDS (mg/l)	305	310	342	500	500
Hardness (mg/l)	24	24	32	150	150
BOD (mg/l)	40	50	80	-	-
COD (mg/l)	260	280	320	-	-
Sodium (mg/l)	1.04	1.04	1.20	200	200
Calcium (mg/l)	0.00	0.00	0.00	200	200
Cadmium (mg/l)	0.01	0.01	0.01	0.003	0.003
Copper (mg/l)	1.01	1.02	1.03	1.000	2.000
Iron (mg/l)	0.02	0.03	0.05	0.300	0.030
Lead (mg/l)	0.00	0.00	0.00	0.010	0.010
Manganese (mg/l)	0.00	0.00	0.00	0.20	0.400
Zinc (mg/l)	0.01	0.01	0.01	3.00	-
Nitrate (mg/l)	9.01	8.57	9.03	50.00	50.00
Nitrite (mg/l)	174.71	173.29	175.14	0.200	3.000
Phosphate (mg/l)	5.90	5.80	6.90		
Sulphate (mg/l)	2.80	3.10	3.24	100	100
Total bacteria counts(cfu/mg)	2.40	4.60	8.10	10	10
E. Coli (cfu/100ml)	0.0	0.0	0.0	0	0
Total coliform counts (cfu/100ml)	1.6	3.0	6.4	10	10

Filter 1 = SSF + GAC + MF, Filter 2 = SSF + GAC
SSF = Slow sand filter, GAC = Granular activated carbon, MF = Magnetic field
SON = Standard Organization Nigerian, WHO = World Health Organisation

Table 3. Values of t-test for the purification of water through the slow sand filters

Treatment	Degree of freedom	Calculated value of t (t_{cal})	Table value of t at $\alpha \leq 0.05$	Effect of passing the water through the filters
Raw water versus Filter 1	17	2.403^{S}	2.110	Significant
Raw water versus Filter 2	17	2.340^{S}	2.110	Significant

Filter 1 = SSF + GAC + MF, Filter 2 = SSF + GAC, Raw water (unfiltered water)
S = the value is significant, SSF, GAC and MF were as defined in Table 2

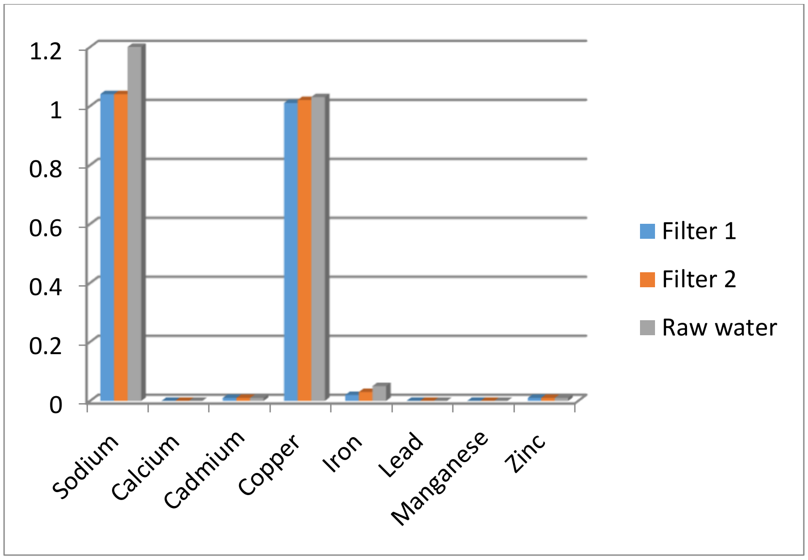

Figure 6 . Properties of cations after filtration through Filters 1, 2 and the Rawwater Filter 1, Filter 2 and Raw water were defined in Table 2.

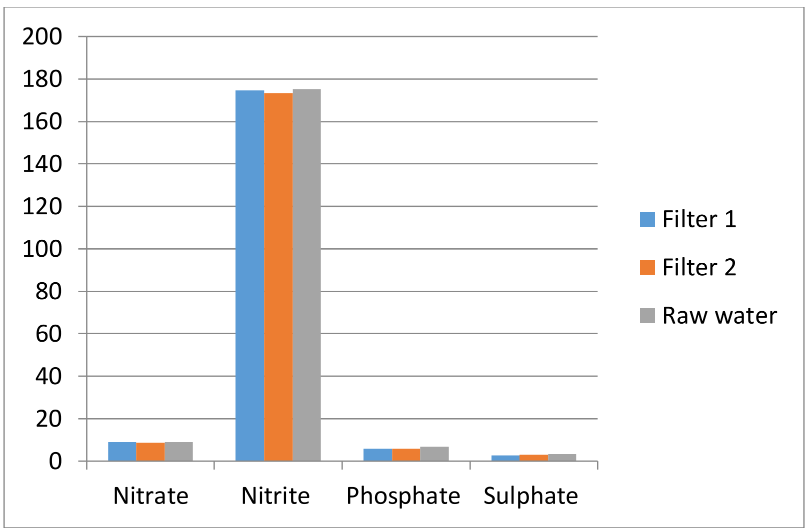

Figure 7 . Properties of anions after filtration through Filters 1, 2 and the Rawwater

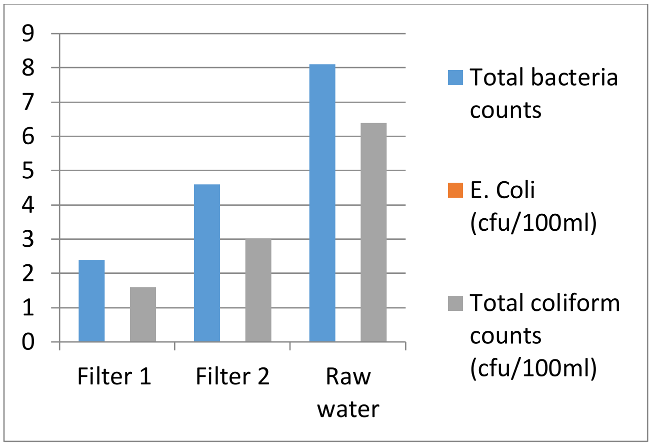

Figure 8. Bacteriological properties of water after filtration through Filters 1, 2 and the Rawwater

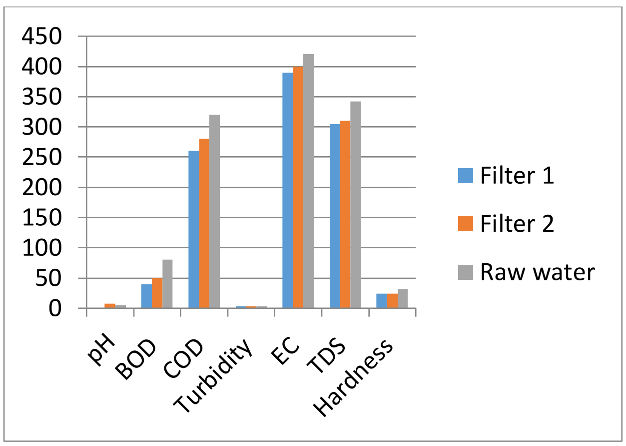

Figure 9. Water hardness and electrical conductivity of water after filtration through the filters compared with the raw water

4.Conclusions

Two slow sand filters were fabricated, one filter was incorporated with GAC only and the second filter was incorporated with GAC and magnetic treatment unit. The two slow sand filters can produce 25 litres/h of clean drinkable water. The slow sand filter with granular activated carbon only reduced the total bacteria counts by 43.21% while the filter with GAC and MF treatment unit reduced the total bacteria counts by 70.37%. The two filters reduced the values of Electrical conductivity, BOD, COD, reduced concentrations of Copper, Nitite, Nitrate, Phosphorus and Sulphate after filtration. The slow sand filter with GAC and magnetic treatment unit reduced the TDS, Turbidity, Hardness and Sodium by 10.82, 3.28, 25.00 and 13.33%, respectively while slow sand filter granular activated carbon only reduced the TDS and Turbidity by 9.36 and 3.28%. Combination of GAC and MF treatment unit in the slow sand filter enhanced the removal of total bacteria counts and total coliform counts.

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