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EFFECTIVENESS OF MULTISTAGE FILTRATION SYSTEM OF WASTE REMOVAL FROM CREEK WATER USING SAND, SUPPORTED ACTIVATED CARBON

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ABSTRACT

There are number of methods of water filtration, each with varying degrees of effectiveness. The general purpose of water filtration is to improve the water's hygiene and aesthetic qualities. The goal of this study is to investigate the effectiveness of multi-stage sand filtration to produce water fit for human consumption by passing it through a bed of sand filters to remove solids and further purifies the water by permitting additional impurities to be adsorbed to the surfaces of the sand particles, and the organic contaminants to be removed or absorbed by the activated carbon introduced into the filter. The filter was designed with a flow rate 50 and 120cm^3/min and as a multi-stage filter that consists of sand particle ranging between 0.15 to 0.30mm in diameter to remove solids and micro-organisms, supported by a granular activated carbon filter to remove the organic contaminants. Ureje creek is one of the sources of water for people of Ado Ekiti, the state capital of Ekiti State, Nigeria. Research was conducted by evaluating the physical, chemical and biological qualities of water samples from the creek. The results revealed high rate of contamination as compared to WHO standard, they were found to be higher than the tolerable limit. Experiment was conducted by passing the water samples through the filter at the designed flow rates mentioned above. Some of the physical, chemical and biological parameters analyzed included; turbidity, dissolved solids, suspended solids, color, coliforms, and mineral content. However, there was a drastic reduction in the impurities after adopting both flow rates. The filter was found to reduce the concentration of suspended solids which aids the transport of micro pollutants by 96%.

INTRODUCTION

In Africa and around the world, there is a significant need for sustainable, cost effective, and reliable drinking water treatment alternatives that provides a safe water supply in communities. Surveys have shown that the rate of deviation from drinking water standards increases compared to the population to be served, (Cleary, 2005). This is clearly due to the high cost of technologies in water treatment, the intensive maintenance, and cost of supply and distribution when compared to the number of people to consume it. These have increased the cost per unit volume of treated water and made it to be higher than necessary. Many small and large communities in Nigeria are faced with challenges of getting portable water due to non availability of technologies to provide treated water as over 95 percent Nigerians do not have access to portable water (Folorunso & Omotoso, 2009). Slow sand filter is a proven, sustainable, and reliable drinking water treatment alternative for most communities with surface creek waters, this can be beneficial to addressing the challenges described above. The process provides treatment through physical filtration of particles and biological removal of organisms and pathogens within an active biological layer of the sand bed. It is a simple method that is relatively easy to operate and understand with little maintenance. This technology is capable of achieving high standards of treatment without the use of coagulants or chemicals. It can operate under a wide range of operational and source water conditions, with little or no process adjustment which makes it robust. It requires less maintenance in terms of cleaning and its operational energy cost are minimal as water can flow through the filter under gravity conditions without the use of pumping and lastly, it does not require the use of specialized equipment and can be constructed with locally available materials, mainly from properly graded sand (Cleary, 2005). However slow sand filter is sensitive to raw water turbidity where consistently high levels of turbidity (30 to 40 NTU) can lead to premature clogging of the filter, decrease the filter run length, and frequent cleaning requirements and additionally, treatment with slow sand filter is less efficient at low temperature ($<2^{o}C$), which hinders biological activities in the filter bed, and finally it is less efficient at removing negatively charged stable suspensions of colloidal matter (Cleasby,1975).

Multistage filtration, consisting of a slow sand filter, preceded by a roughing filter which serves as a rapid sand filter can overcome some treatment limitations of slow sand filter, it can provide a reliable treatment alternative for creek surface water sources of variable turbidity and temperatures, it is a multi barrier treatment process in which waterborne particulate matter and pathogens face a series of treatment barrier which may produce an effluent water quality. The roughing filter consisting typically of two to three layers of gravel media used to attenuate turbidity peaks, especially in highly turbid water and reduce the solid loading on the slow sand filter, hence increasing its run length, and improving effluent quality (Ogedengbe,1982). The roughing filter may also allow the slow sand filter to operate at higher than typical hydraulic loading rates. It provides a large surface area for the sedimentation of colloidal matter, and provides additional biological treatment and hydraulic retention time, which may be important in case of highly contaminated creek water (Cleary, 2005). By investigating the performance of multistage filter under a range of creek raw water conditions, a range of small system conditions could be established, for which multistage filtration is a viable drinking water treatment option to remove suspended solids which transport micro pollutants that causes cholera and related diseases in drinking water. This work will further elucidate the reliability, cost effectiveness of multistage system for water treatment in Nigerian communities.

Water Quality Standards

Water quality is a technical term that is based upon the characteristics of water in relation to guideline values of what is suitable for human consumption and for all domestic purposes, including personal hygiene. Components of water quality include microbial, biological, chemical and physical aspects.

Microbial Aspect: Drinking water should not include microorganisms that are known to be pathogenic. It should not also include bacterial that would indicate excretal pollution. The primary indicator of which is coliform bacteria that is present in the feces of warm-blooded organism. Chlorine is the usual disinfectant, as it is readily available and inexpensive; unfortunately, it is not fully effective as currently used against all organisms.

Biological Aspect: Parasitic protozoa and helminthes are also indicators of water quality. Species of protozoa can be introduced into water supply through human or animal fecal contamination. Most common among the pathogenic protozoan are *Entamoeba* and *Giardia.* Coliform are not appropriate direct indicators because of the greater resistance of protozoan to inactivation by disinfection. Drinking water sources that are not likely to be contaminated by fecal matter should be used where possible due to the lack of good indicators for the presence or absence of pathogenic protozoan.

Chemical Aspect: chemical contamination of water sources may be due to certain industries and agricultural practices, or from natural sources. When toxic chemicals are present in drinking water there is potential that either acute or chronic health effects. Chronic health effects are common than acute effects because the level of chemicals in drinking water are seldom high enough to cause acute health effects. Since there is limited evidence relating chronic human health conditions to specific drinking water contaminants, laboratory animal studies and human data from clinical reports can be used to predict adverse effects (Folorunso & Omotoso, 2009).

Physical Aspect; The turbidity, color, taste, and odor of water can be monitored. Turbidity should always be low, especially where disinfection is practiced. High turbidity can inhibit the effects of disinfection against microorganisms and enable bacterial growth. Drinking water should be colorless, since drinking water coloration may be presence of colored organic matter. Organic substances also caused water odor and other factors like biological activities and industrial pollution. Taste problem relating to water could be indicators of changes in water sources or treatment processes. Inorganic compounds such as magnesium, calcium, sodium, copper, iron, and zinc are generally detected by the taste of water.

W.H.O guidelines for drinking water (2009)

S/N	Constituents	Health Effects	Permissible Limit
	Physical Parameters		
1	Color	Cosmetic effect, no proven health hazard or risk	15 pt/co unit
2	Odor	No reported direct effect	3 threshold count
3	Taste	"	-
4	Turbidity	Harbours pathogenic organism	5 NTU
5	Temperature		33-44 ^{o}F
	Chemical Parameters		
6	PH	No direct effect	6.5 - 8.5
7	Alkalinity as $CaCO_3$	No direct effect	30 – 500 mg/l

8	Chloride	Corrosion of metals, taste changes in water	250 mg/l
9	Hardness as $CaCO_3$	Inverse relationship to cardiovascular diseases	250 mg/l
10	Iron	Essential nutrient, no proven health hazard	0.3 mg/l
11	Nitrate	Gastric cancer Mathaemoglobinaemia in infants	3.0 mg/l
12	Sulphate	Catharsis, dehydration, gastrointestinal irritation, taste and corrosion of distribution system	250 mg/l
13	Total dissolved solids	Objectionable to consumers, no proven health effects	500 mg/l
14	Manganese	Neurotoxin at high levels	0.05 mg/l
15	Sodium	Hypertension, cardiovascular diseases	200 mg/l
16	Lead	Prove fatal due to lead poison	0.1 mg/l
17	Copper	Exhibits taste	1.0 mg/l
18	Calcium		200 mg/l
19	Magnesium		150 mg/l

Table1. Showing WHO guidelines for drinking water (WHO, 2009)

Theory of Filtration

The process of filtration involves the passage of water or fluid to be filtered through a bed of granular materials with or without the addition of chemicals. As water passes through the filtering media, impurities in the water which include suspended solids, colloidal matter, chemical constituents as well as bacteria are removed or at least reduced to an acceptable level. When properly operated, a filtration plant including coagulation, flocculation, and setting can be expected to remove 90 to 99.9% of the bacteria, protozoa and viruses, a great deal of odor and color, and practically all of the suspended solids. (Ogedengbe, 1985).

The mechanism of removal of these impurities are summarized by (Babbit et al 1967) and (Metcalf and Eddy Inc 1972) as straining (mechanical and shear contact), Sedimentation, Interception, Adhesion, Absorption (both physical and chemical), electrical effects and biological growth and changes. (Metcalf & Eddy, 1972).

- ***Mechanical straining*** is a physical mechanism involving the removal of large particles especially at the surface of the medium. During the passage of water through the medium, the particles which are unable to pass through the pore of the medium are retained.
- ***Sedimentation***, ***adhesion***, ***absorption*** and ***electronic attraction*** are responsible for the removal of small particles of suspended matter and some bacteria. The voids in the bed acts as a minute sedimentation chamber where forces of gravity helps the particle to settle.

- ***Biological growth*** is changes brought about during filtration as a result of life processes in living cells. This is most significant in slow sand filters where it results in changes in the water been filtered (Babbit et al, 1967).

Generally, the slow sand filter is designed such that at the slow flow rate of the water through the fine sand, coarser suspended solids are caught on or near the surface of the bed to form a very little fine porous layer having a large total surface area of channels of pores (Fox & Cleasby, 1966).

MATERIALS AND METHODS

Multistage filtration of samples of raw water from Ureje creek was investigated; samples were collected daily between 7.00 and 9.00am. Each day water samples were collected using two samplers approximately twenty liters each over a period of ten days, the samples were being stored until laboratory analysis within two days of collection. A total of 20 water samples were collected for this work. The samples considered in this study abstract surface water as a source of drinking water with different factors influencing the raw water quality.

A typical treatment sequence consists of collection, temperature monitoring, screening and filtration was adopted.

Laboratory Methods

Water samples were not filtered prior to laboratory analyses. The effluents filtered from the raw water were also analyzed after filtration processes.

The physical, chemical and biological parameters for the raw water samples were performed using simple analytical techniques. Organic matter was measured on the raw (unfiltered) samples using spectrophotometer by wavelength analysis, A DRT 100 turbid meter was used to monitor the turbidity of raw water and the processed effluent, the water samples demonstrated high turbidity and color. There was no dilution performed on water samples.

Filter Media

The filter media is the important component of the filter which actually removes the particles from the water to be treated. Filter media is most commonly sand, though other type of material can also be used, usually in combination with sand. Sand use in rapid filters is coarser than the one use in slow sand filters. The larger sand has larger pores which do not get filled up quickly with particles removed from water. Coarse sand also cost less and more readily available than the fine sand use in slow sand filtration. Most rapid sand filters contain 60 to 70 cm thickness of sand. The sand used as filter media in rapid sand filter is generally of effective size of 0.4 to 0.7 mm with uniformity coefficient of 1.3 to 1.7. The standing water depth over filter varies between 1.0 to 2.0m. The filter media was pre-sieved and graded to size fractions. Bulk of river sand deposits were collected, purified with 10% hydrochloric acid and distilled water, it was also air dried. The adequate selection of sand includes size grading characterized by the effective size diameter d10, and the uniformity of coefficient, uc = d60/d10. The d10 was small enough to produce safe water and equally prevented the penetration of clogging matter. The quantity of sand weighed was $1500g$. The coarsegrained material was crushed and pre-treated to pass through a sieve ranging from ***(4.75, 3.35, 2.36, 1.18, 0.600 and 0.425)*** mm respectively by the use of a mechanical shaker for 15 minutes to determine the particle size distribution.

Experimental Design of Multi Stage Filter

Treatment unit	**Number of units**	**Filtration area(m^2)**	**Filter medium size (mm)**	**Filter medium length (m)**
Rapid (Roughing)	2	1.5	0.3-0.80	0.6
Slow sand	2	1.25	0.2-0.3	0.4
Activated carbon(Granular)	1	1.25	0.5 Uc = 1.57 D_{10} = 0.23mm	0.05

Table2. Showing the design parameters for the multistage system.
Uc = Uniformity coefficient
D10 = Effective diameter

Multistage filtration process effectively treat raw water with a wide range of quality to high standards without the use of pretreatment chemicals.

Multistage filtration process has the following operation units;

- The roughing filter
- Slow sand filter
- The activated carbon unit

The roughing filter consists of coarse gravel with diameters ranging from 0.30 to 0.80mm, with a design flow rate of $120cm^3$/min. The primary purpose of roughing filter is to protect the slow sand filter from excessive solids loading; larger solids and organisms are removed from the raw water by the roughing filter. The roughing filter removes up to 80 percent of the suspended solids. The slow sand filter is the core of the multistage filter. It consists of a large bed of fine sand obtained from a river bed of 350mm deep. It was designed to flow at a rate of $50cm^3$/min. No chemical pretreatment was used to remove turbidity in slow sand filters. The water was filtered at a slow rate and a biological layer developed at the surface of the sand, this process acted to remove the turbidity. Activated carbon unit is a layer of sand topped by granular activated carbon; it is an excellent support media for removal of biological materials and will also reduce any oxidants in the water. In the roughing filter water, water flow downward through a series of media layers: 60cm depth 0.3-0.80 mm diameter, after the roughing filter, water the slow sand filter and flow downward through 35cm depth of 0.2-0.3 mm diameter sand media. The sand was supported by the activated carbon 5cm deep and 0.2mm diameter.

Analyses of Results

The summary of the results for physical, chemical and biological parameters are shown below, Filter influent samples were analyzed in 1 to 2ml volumes and filter effluent samples were analyzed in volume ranging from 20 to 50 ml. These sample volumes were generally chosen to yield the total solids and coliform contents per batch. Sample handling, identification, preservation were properly done for quality control and assurance. The samples were analyzed at three stages, the raw water, treatment by slow and rapid filtration rate, and finally by multistage filtration technique.

Correlations of the effluents from the slow and rapid sand filters with the raw water samples were obtained by the least square regression method (Christensen et al, 2001). The results are shown in the figures 2a, 2b, 3a, and 3b.

Results of Physical Parameters

S/N	Parameter	Raw Water Quality	FILTERED WATER Quality(slow) flowrate(50cm^3/min)	FILTERED WATER quality(multi) F.R (120/50cm^3/min)	W.H.O STANDARD	
					Tolerable	Permissible
1	Colour (Hu)	10	5	3	15PT/CO	-
2	Odour (Threshold No)	40	15	11	< 2	< 3
3	Turbidity (NTU)	15.5	7.05	3.45	5	25
4	Temperature (℃)	25.6	24.5	25.0	10.0	15.5
5	Appearance	NOT CLEAN	FAIR	CLEAR	VIRTUAL ABSENT	-

Table3, showing results for physical parameters

Results of Chemical Parameters

S/N	Parameter	Raw water quality	FILTERED WATER Quality(slow) flowrate(50cm^3/ min)	FILTERED WATER quality(multistage) f.r (120 and 50 cm^3)	W.H.O STANDARD	
					Tolerable	Permissible
1	Ph	7.8	7.5	7.5	6.5 – 8.5	6.5 – 9.2
2	Total Solids (mg/l)	850.5	552.0	122.0	-	-
3	Suspended Solids (mg/l)	340.0	96.0	21.0	-	-
4	Total Dissolved Solids (mg/l)	510.5	342.0	210.0	500	1200
5	Total Hardness (mg/l)	220	140	125	100 as $CaCO_3$	-
6	Chloride	41.50	36.60	40.26	250	-

	(mg/l)					
7	Calcium (mg/l)	35.27	17.6	12.4	75	-
8	Magnesium (mg/l)	5.34	4.37	4.29	50	150
9	Alkalinity (mg/l)	12.2	10.9	10.2	200 as $CaCO_3$	-

Table4, showing results for chemical parameters

Result of total number coliform present on each of the plate examined on M-Endo broth agar incubated at 35℃

Sample No. Source/Location	**Flow Rate** $Cm3/min$	**Total Coliform count** $(\boldsymbol{C.F.U\ x\ 10^5})$	**Average Count** $(\boldsymbol{C.F.U\ x\ 10^5})$	**Plate Count Remarks**
Raw water sample (Ureje Creek)		180	90	Dangerous / unsatisfactory
Water sample after filtration (Slow rate)	50	28	14	Unsatisfactory
Water sample after filtration (MSF)	120/50	16	06	satisfactory

Table 5, showing results for biological parameters

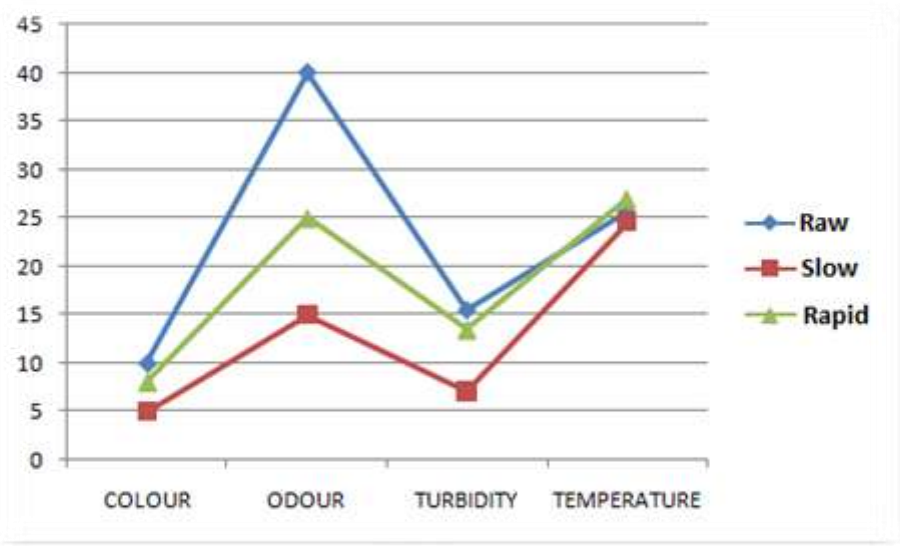

Figure2a

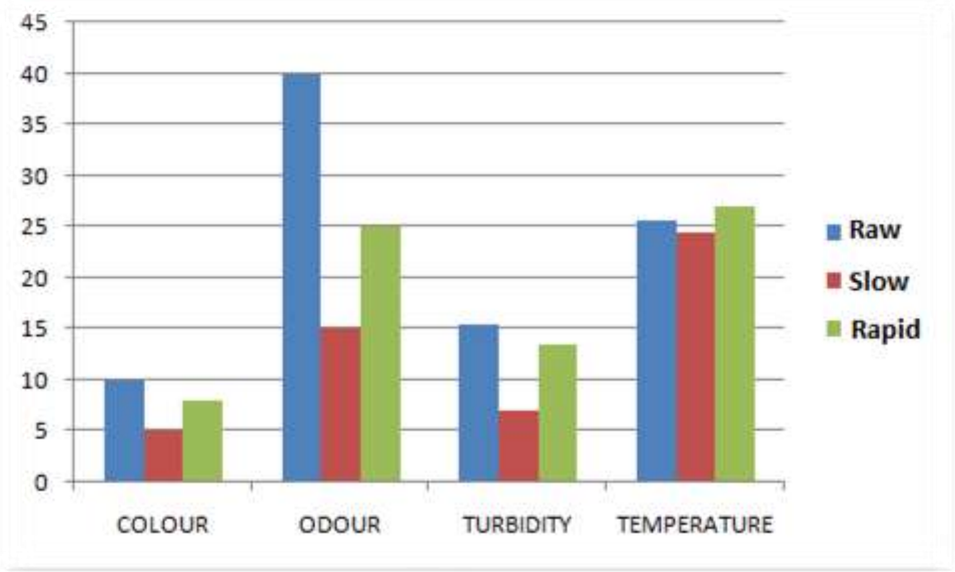

Figure2b. Figures 2a&b. showing correlations of filtered physical parameters with the raw samples

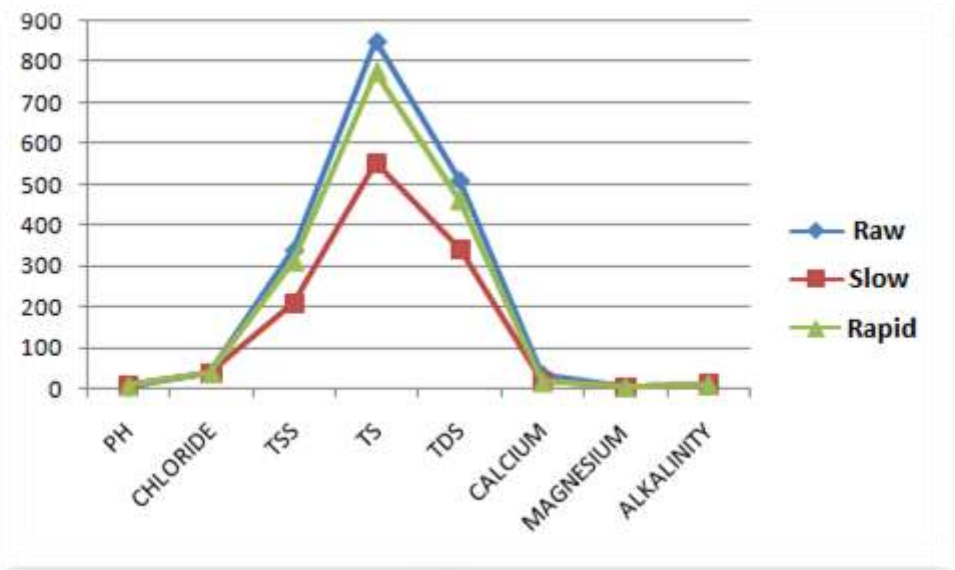

Figure 3a.

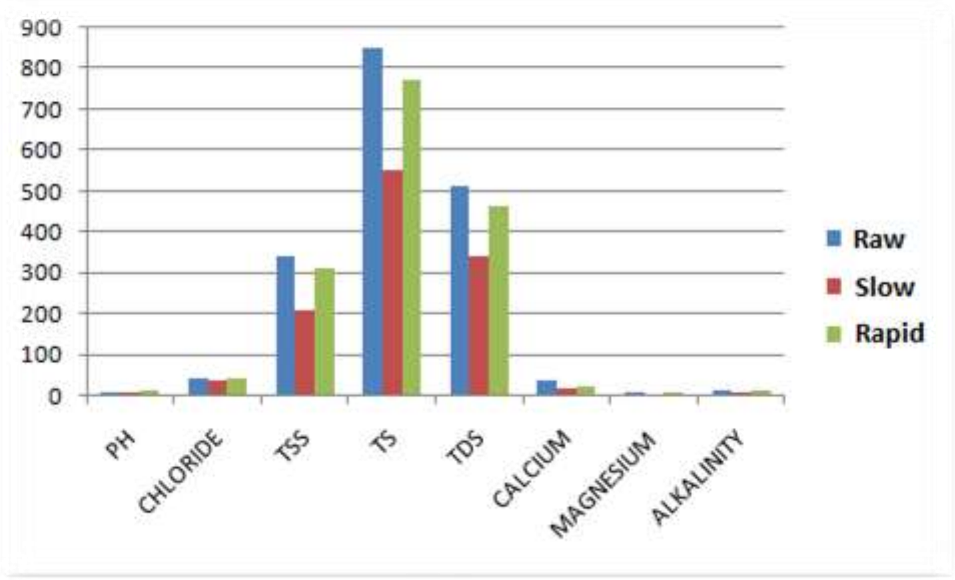

Figure3b. Figures 3a&b. showing correlations of filtered chemical parameters with the raw samples

DISCUSSION OF RESULTS

The results show that the combination of the two stage filters much improves the treatment of the raw water. During the entire study the water temperature ranges from 22 to 28^{0}C. The performance of slow sand filter was significantly improved by the multistage system. Granular activated carbon filter was a consistence contributor to the removal of organic contaminants. Slow sand filtration produced an effluent of 7.05NTU and in a more mature way; the multistage filter produced an effluent below 4.0NTU. This was a great improvement on the performance of slow sand filter. Multistage system performed best with the removal of suspended solids from the raw water. The can be attributed to the deeper bed depth of the combined filters. The filter was found to reduce the concentration of suspended solids by 96%. The results of the experiments carried out on the raw samples show that the creek is seriously polluted with high loads of pollutants, the results also observed characteristic coliform organism presence in the raw water sample before filtration. From tables 4, 5 and 6 showing results for parameters treated, it would be noted that there was a reduction in the pollution loads (physical and chemical) and coliform counts (pathogens) with respect to multistage filtration system. Moreover there was a great improvement on the quality characteristic of the samples before and after treatment with both slow sand and multistage filters. The highest variation from the raw sample quality was observed with the multistage filtration system, while the least was observed with rapid or roughed bed when it was used alone for filtration. The qualities after multistage filtration are within the WHO standard for drinking water. Though there were some levels of treatment with rapid and slow sand filters when separately used for raw water treatment. Figures 2a, 2b, 3a, 3b, shows the correlation coefficients of the effluents parameters from both rapid and slow sand filters with the raw water samples. From the figures, it is observed that the correlation coefficients of the effluents parameters do not give any appreciable removal of pollution when compared to the raw water samples. It also shows better performance for slow sand filtration system as it is less correlated with the raw samples than the rapid filtration system.

CONCLUSIONS

The performance of multistage filter has been judged to be satisfactory by the results shown above; from the results multistage filter can adapt itself to the type of raw water and concentration of contamination. With the removal of suspended solids by 96%, the system proved to give higher removal efficiencies for water that is higher in contamination which are primary causes of cholera and other related diseases. The system also has a great potential to reduce the physical chemical and bacteriological risk associated with surface water sources. Multistage filtration system is a good alternative to improve the physical, chemical and bacteriological quality of the raw water, the relatively simple design facilitates the use of local materials and local manpower which also reduce the cost operation and maintenance.

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