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RESEARCH ARTICLE

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EFFECT OF CHARCOAL-SAND FILTRATION, CHEMICAL DISINFECTION AND SOLAR HEATING ON BACTERIOLOGICAL AND PHYSIOCHEMICAL QUALITY OF SURFACE WATER

ABSTRACT

In our effort to contribute to availability of safe drinking water, we designed a laboratory scale and prototype charcoal- sand filtration (CSF) reactor (31.5 by 35.0 cm) for the treatment of surface water for rural dwellers. The qualities of charcoal-sand filtered solar treated water samples were monitored using standard plate count technique for total bacteria and total coliforms. Bacterial isolates from CSF water were evaluated for antibiotic resistance pattern. Sensory evaluation of the treated surface water was done using a 20- man panel and the result was statistically analyzed. Charcoal-sand filtration of the raw water produced reduction of total viable bacteria counts (TVB) of 91.3% and 77.0% of TCC. The CSF in combination with solar disinfection (SODIS) resulted to reduction by 92.7 % and 97.4% of TVB and TCC respectively. The CSF-chlorinated water and CSF-citrated water were free of bacteria. Thirty-Six Gram-negative bacterial isolates were recovered from raw water samples. They comprised Escherichia coli (36.1%), Enterobacter aerogenes (24.1%), Klebsiella pneumoniea (10.8%), Salmonella Typhi (8.4%), Shigella dysenteriae(8.4%) and Pseudomonas aeruginosa (12.0%). No significant difference was noticed between the overall acceptability and organoleptic properties in terms of taste, odour as well as clarity of CSF-SODIS water and CSF-chlorinated or CSF-citrated water (Probability=95%). The physic-chemical quality of CSF-SODIS water met the standard limit for drinking water. Hence, CFS-SODIS may be recommended for surface water treatment in rural communities to prevent outbreak of waterborne diseases

Key words: charcoal-sand filtration, solar disinfection, drinking water, antibiotic resistance, coliform bacteria, waterborne disease

INTRODUCTION

Environmental risk assessment today reveals that the exposure to waterborne microbial pathogens needs to given higher priority in regulatory programs especially for domestic water supply (Craun 1986, 1988, Akpan, 2004). People living in rural or semi-urban areas do not have access to potable water but to surface water fromrivers, streams, and wells (Oluyege et al., 2011) These water bodies have high level of contaminant which leads to water borne disease. Since the availability of good quality water determines the quality of life, potable water should be given a serious attention in urban and rural communities (Edema et al., 2001, Rose etal., 2006, Okonko et al., 2008).

In developing countries,90% of the industrial waste still goes untreated into river ,steam (Olayemi and opaleye, 1990). In most rural settlement or developing countries, particular in Nigeria, spring, wells, stream, lake, serve predominant as major source of water supply for drinking and other domestic purposes. In most cases, ignorance, poverty, make many people to consume untreated water (WHO, 2004). The consequence of this is outbreak of deadly disease. According to World health organization (WHO, 2004) over 1.1 billion people lack access to improved drinking water supply, 88% of the 4billion annual cases of diarrhoea are attributed to unsafe water and inadequate sanitation and hygiene. Also 1.8million people die as a result of diarrhea each year. Since the waterborne disease become alarming and mortality rate is increasing every year. The Environmental Protection Agency (EPA,2008) standard for acceptable drinkable water for coliform count should be zero.

Conformation with microbiological standard is of special interest because of capacity of water spread disease within a large population (Okonko et al., 2008, Jamil, et al., 2009). Although the standard varies from place to place, the objective anywhere is to reduce the possibility of spreading water borne diseases. (Edema et al.,2001).Cholera is the classic example of severe watery diarrhea. The diarrhea fluid can amount to 20 liter a day and because of it appearance, has been described as rice water stool, vomiting , diarrhea, severe dehydration followed by collapse, shock and many cases of death

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Other examples of waterborne disease caused by bacteria are gastrointesterocolitis (caused by klebsiella and E. coli (Alam et al., 2007). From time immemorial, the use of chlorine for disinfection had been widely accepted but recent research works has revealed the potential of chlorine reaction with organic compounds may produce carcinogens. (Ref). In the recent times, several approaches are being considered as solution to the problems of providing good quality and potable water for rural populace especially in developing word (Qiu et al., 2004, Rose et al., 2006). Hence, the objectives of this work were to investigate the antibiotic susceptibility of surface water for public health assessment and also to determine the effectiveness of charcoal-sand filter media solar heating reducing the bacterial density of surface water

MATERIALS AND METHODS

Collection of surface water samples

Surface water samples were collected from Omisanjana Streamwhich passes through the metropolis and receives domestic waste water along Ilawe Road in Ado-Ekiti, Nigeria (Odeyemi et al.,2012). Water samples (250 mL x 3) were collected at the depth 60.3 cm into sterile bottles and transported in ice-pack to the laboratory for bacteriological and physicochemical analyses.

Preparation of charcoal-sand filter and solar reactors

The charcoal-sand filter reactor was prepared by placing granite stones with mean diameter of 47.9mm at the bottom of the tank to a height of 9.0cm. This was followed by layer of gravel of mean diameter size of 18.61mm of height and fine sand (mean size 0.05mm mesh) of 10.5cm in height. The large stone, gravel and sand layers were overlaid with amorphous charcoal of 4.5cm in thickness followed by another layer of fine sand 2.0 cm in height (Fig. 1 and Plate 1). Each layer of the filter media were separated using sterile muslin cloth. All the filter media were sterilized in a hot-air oven at 100^{o}C for 2hrs before package. The solar reactor was a black painted wooden box (64cm x 57.4cm x 43.0cm), covered with transparent glass for penetration of sun rays. The box had an opening sliding door through with filter water in sealed plastic bottles are loaded (Plate 3)

Water filtration, chemical disinfectionand solar heating procedures

Flocculated (addition of 75.0g aluminum potassium sulfate in 25 Litres) and unfloculated raw water samples (25Litres) were filtered through the charcoal sand filter media at a flow rate of l.5L/hour. The filtrate was then collected for solar heating processes, chlorination and citric acid treatment. For solar disinfection, filtered water samples in 0.5L-sized transparent PET-bottle (McGuigan et al., 2012) were exposed to sunlight at a mean temperature of 45^{o}C for 6hours (9:00 am -3:00 pm) at latitude of 5^{o}20'E and lonutude of 7^{o}45'N in the constructed black painted wooden box described above (Plate 3). For chemical disinfection, filtered water samples were added with chlorine or citric acid at permissible concentration of 1.5mg/L and 1.25gm/L respectively with 6 hrs-contact (Udoma, 2005). The treated water samples were subjected to bacteriological and physicochemical analyses.

Determination of bacterial population of the water samples

The total bacterial and coliform concentrations of the treated water samples were determined using standard plate count techniques. Ten-fold dilutions of the water samples were done and 1.0ml of dilutions 10^{-3} to 10^{-5} were inoculated in molten agar media: Standard plate count agar (SPCA) for total bacterial count and MacConkey agar (MAC) for total coliform count (Franziska, 2010). The mixtures were allowed to gel in sterile petri-dishes. The plates were incubated in each case at temperature of 37^{o}C for 18hrs. The developed bacterial colonies were counted on colony counter. The percentage reduction of bacterial densities was calculated as (Nr – Nt/Nr) x 100, where Nr is bacterial count of raw water and Nt is bacterial count of treated water.

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Isolation and characterization of Gram-negative bacteria from raw water samples

Pour plate technique was used for isolation of bacteria 1ml of dilution 10^{-2} and 10^{-3} were inoculated in molten nutrient agar, MacConkey agar, Eosin methylene blue (EMB) agar, Salmonella-shigella (SS) agar and then were poured in sterile Petri-dishes. The plates were allowed to set and then incubated at 37°C for 24 hours .The developed colonies were isolated by sub-cultured on to fresh agar media until pure cultures of gram-negative bacterial isolates were obtained. Morphological and biochemical examination were conducted on the isolates. The biochemical tests were catalase production, sugar fermentation (glucose, sucrose, lactose, manitol, maltose and fructose), indole production, methyl red, voges proskauer, urase, citrate utilization test and oxidase and data obtained were interpreted based on Cowan and steel's manual for identification of medical bacteria (Barrow and Feltham,2003, Laboffe and Pierce, 2011)

Physico-chemical analysis of raw and treated surface water samples

Conductivity, pH and total dissolved solid (TDS) were determined using PH/EC/TDS/Meter model number H19813/0. Total hardness and turbidity of the raw and treated water samples were determined using Lovibond kit 424 (Tintometer Limited, Salisbury, England) and Turbidometer TBN 80120-1(Shanghai China Instrument and meter Limited) respectively.

Determination of organoleptic properties of treated water

The sensory evaluationof the treated water was done using a Twenty-man panel based on the consent of the members to participate in the evaluation. The test parameters were clarity, taste, odour, appearance and overall acceptability with scores of 0 to 5. The data obtained were subjected descriptive statistical analyses using one-way ANOVA at $P \leq 0.05$ and Duncan multiple range test. The statistical package used for the analysis was SPSS 11.0.

RESULTS AND DISCUSSION

The raw water samples from Omisanjana stream had total bacterial count ranging from 2.75×10^6 and 3.0×10^6 cfu/ml while coliform count ranged from 2.35×10^6 to 2.45×10^6 cfu/ml indicating lack of conformity with the standard of the World Health Organisation for drinking (WHO, 2004; Okonko et al., 2008). The discributions of Gram-negative bacteria isolated from raw surface water samples were Escherichia coli (36.1%), Enterobacteraerogenes (24.1%) Pseudomonasaeruginosa (12.0%), Klebsiella pneumoniae (10.8%) , SalmonellaTyphi,(8.4%), and Shigelladysenteriea (8.4%) as shown in Figure 2.

The presence of coliform suggests that certain section of the water is contaminated with faeces either from human source or animal source. Filtration of the raw water samples through freshly prepared charcoal-sand filter, did not produce appreciable good quality drinking water interms of physiochemical parameters , total bacterial counts and total coliform counts. However, the effectiveness of the charcoal-sand filter media increased with increase in the number of runs or filtration processes of the raw waterthrough the media (Figure 3). The newly charged charcoal-sand filter removed only 10% of coliform and 13% of the total bacteria (Figure 3). However, 70% of the total bacteria count and 77% of the coliform count were removed after 5th run (Table 1).

It is also interesting to note that charcoal-sand filtration (CSF) in combination withsolar disinfection (SODIS) removed 92% to 97% of total bacteria and coliform from surface water samples (Table 1). Total removal of coliform and aerobic bacteria was effected by treatment with chlorine and citric acid concentration of 1.5mg/L and 1.25gm/L respectively

However, the treatment with citric acid at concentration of resulted to increase in pH of water samples. Chlorination of water has been found to be the most effective of all water purification methods (Alam et al.,2007). Exposing the water to sunlight at temperature range of 40^0C- 45^oCin solar reactors for 6 hours was also effective in reducing bacterial density. Enterococcus faecalis and Vibrio cholerae have been reportedto be inactivated by solar treatment (Joyce et al., 1996, Rose et al., 2006). Lethal effect of solar disinfection on some water pathogens been observed to result from damage DNA in bacterial cell (Hadar et al., 2007, Matallana-Surget and Ruddy, 2013).

The physicochemical parameters were affected by charcoal-sand filter in that the total hardness of water reduce from 60mg/L to 20mg/L. The total dissolved solid was reduced from 120 to 104 mg/L, turbidity was reduced from 0.46 to - 0.12NTU, the pH of the water from 7.25 to 7.10. thus making the treated water samples to conformed with WHO standards for drinking water.(Table 2). However, it is noteworthy that filtration of raw surface water samples through the charcoal-sand filter media appreciably reduce the turbidity (Plates 1 and 2). Chlorination or addition of citric acid for water disinfection at appropriate concentration was effective in terms of deactivation of microorganisms and also have appreciable effect on the physiochemical qualities of the water. The total dissolve solids of chlorinated water was 183.5mgL^{-1} while that of citric acid treated water was 305mgL^{-1} with conductivity of 0.43mS$cm^{-1}$and pH of 6.65 It has also been reported that activated charcoal can adsorb some organic chemical compounds from water (Adeyemo, 2003, Adeyemo et al., 2008; Ajayi and Akonai, 2003). The result of this study has demonstrated that water sanitation can be achieved using charcoal-sand filtration and solar disinfection especially in rural communities.

Duncan Multiple Range Test revealed that raw water samples differ significantly from treated water samples in terms of odour, clarity, appearance and overall acceptability. The Duncan Multiple Range show that no significant different in terms of overall acceptability between filtered water, solar disinfected water and water treated with citric acid at concentration of (1.5mg/L) among the 20-men panel (Table 3). Although chlorine and citric acid treated charcoal-sand filtered water samples were rated more acceptable for drinking (Table 4), it is still imperative to introduce charcoal-sand filtration and solar disinfection of surface water for drinking purpose in rural communities for affordability

CONCLUSION

It could be possible to develop a mini water treatment plant using charcoal-sand filter and solar disinfectiontechniques in rural communities having no access to potable water. Chlorination which is widely acceptable for water disinfection and prevention of waterborne infectionsbut studies have shown that bioaccumulation of chlorine compounds in human body could lead to serious health risk and physiological disorders. Hence, there is a need for alternatives methods of water treatment and disinfection such as sand-charcoal filtration and solar disinfection which are effective, affordable and accessible to the rural and low income communities.

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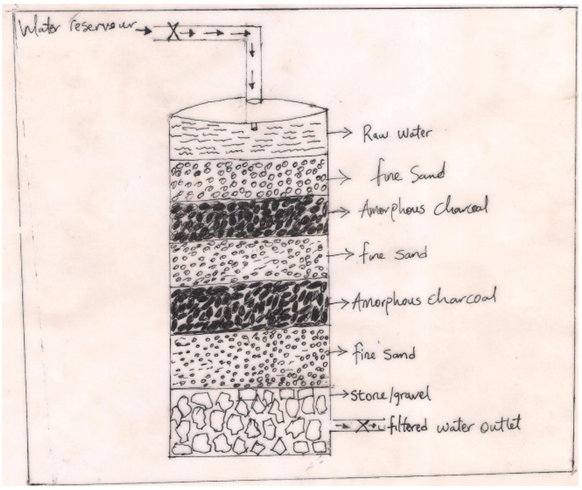

Fig.1. Packaging of charcoal-sand filter media

Plate 1: Laboratory scale charcoal-sand filter set-up

Plate 2: Charcoal-Sand filtered water and raw water   plate 3

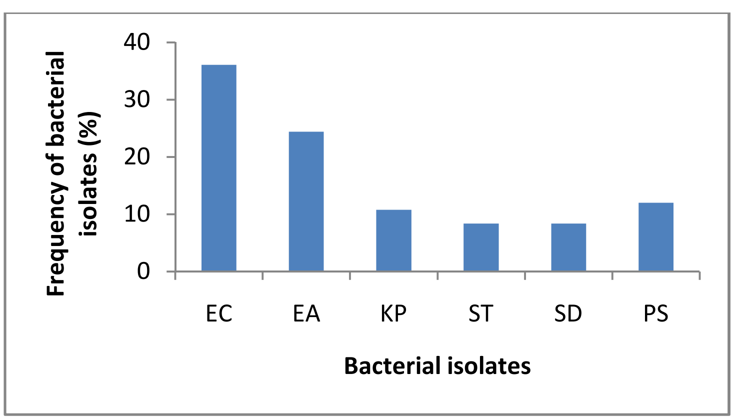

Figure 1: Distributionof isolation of Gram-negative bacteria from raw surface water Samples (EC, Escherichia coli, EA, Enterobacter aerogenes, KP, Klebsiella pneumoniae, ST, Salmonella typhi, SD, Shigella dysenteriae, PS, Pseudomonas aeruginosa)

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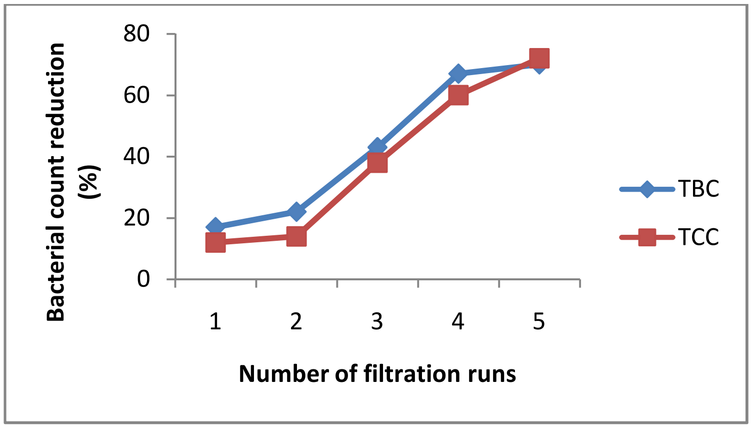

Figure 3: Changes in the bacterial filtration efficiency of charcoal-sand filter media (TBC, total bacterial count; TCC, total coliform count)

Water Samples	Mean bacterial counts			Reductions(%)	
	TVB(cfu/ml)	TCC (cfu/ml)	TVB/TCC Ratio	TVB	TCC
RWS	$2.75x10^6$	$2.35x10^6$	1.17	0.00	0.00
FRW	$2.40x10^6$	$2.00x10^6$	1.20	12.7	14.8
CSF	$2.4x10^5$	$5.4x10^5$	0.44	91.3	77.0
CSF-SODIS (6Hrs)	$2.0x10^5$	$6.00x10^4$	3.33	92.7	97.4
CSF-CLO	0.00	0.00	0.00	100.0	100.0
CSF-CIT	0.00	0.00	0.00	100.0	100.0

Table 1: Total viable bacterial (TVB) and coliform counts (TCC) of charcoal-sand filtered and solar treated surface water

*Raw water (RWS), flocculated water (FRW), charcoal-sand filtered water (CSF), solar disinfection (SODIS), charcoal-Sand filtered-chlorinated water (CSF-CLO), charcoal-Sand filtered-citrated water (CSF-CIT), total viable bacterial (TVB), total coliform count (TCC)

Physicochemical parameter	Mean values						WHO standard
	RW	FRW	CSF	CSF/SODIS	CSF-CLO	CSF-CIT	
pH	6.25	7.88	6.95	6.80	6.45	6.65	6.5 -8.5
EC ($mScm^{-1}$)	0.195	0.16	0.15	0.14	0.38	0.43	1.0
TDS (mg/L)	124.0	112.5	109.0	103.0	183.5	305.0	500
Turbidity (NTU)	0.46	0.58	0.87	0.16	0.85	0.76	5.0
Hardness (mg/L)	65.3	60.0	20.0	20.0	35.6	40.0	100
Alkalinity (mg/L	3.45	3.26	3.35	3.20	3.86	2.76	100

Table 2: Physicochemical properties of charcoal-sand filtered and solar treated surface water

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Raw water (RWS), flocculated water (FRW), charcoal-Sand filtered water (CSF), solar disinfection (SODIS), charcoal-Sand filtered-chlorinated water (CSF-CLO), charcoal-Sand filtered-citrated water (CSF-CIT), electrical conductivity (EC) , total dissolved solid (TDS).

Qualiity parameter	Samples	N	Mean	Std. Deviation	Std. Error.	95% Confidence interval for mean	
						Lower Bound	Upper Bound
Appearance	CSF-CLO	20	4.70	0.571	0.128	4.43	4.97
	CSF-CIT	20	4.30	0.801	0.179	3.92	4.68
	CSF-SODIS	20	4.15	0.587	0.131	3.88	4.42
	CSF	20	4.25	0.716	0.160	3.91	4.59
	RW	20	1.00	0.000	0.000	1.00	1.00
	Total	100	3.68	1.483	0.148	3.39	3.97
Odor	CSF-CLO	20	4.65	0.489	0.109	4.42	4.88
	CSF-CIT	20	4.25	0.550	0.123	3.99	4.51
	CSF-SODIS	20	3.75	0.550	0.123	3.49	4.01
	CSF	20	3.85	0.671	0.150	3.54	4.16
	RW	20	1.75	0.716	0.160	1.41	2.09
	Total	100	3.65	1.167	0.117	3.42	3.88
Taste	CSF-CLO	20	4.30	0.733	0.164	3.96	4.64
	CSF-CIT	20	4.10	0.553	0.124	3.84	3.36
	CSF-SODIS	20	3.35	0.988	0.221	2.89	3.81
	CSF	20	3.40	1.046	0.234	2.91	3.89
	RW	20	1.50	0.889	0.199	1.08	1.92
	Total	100	3.33	1.303	0.130	3.07	3.59
Clearity	CSF-CLO	20	4.20	1.005	0.225	3.73	4.67
	CSF-CIT	20	4.10	1.071	0.240	3.60	4.60
	CSF-SODIS	20	3.65	0.745	0.167	3.30	4.00
	CSF	20	3.55	0.759	0.170	3.19	3.91
	RW	20	1.50	1.100	0.246	0.99	2.01
	Total	100	3.40	1.356	0.136	3.13	3.67
Overall Quality	CSF-CLO	20	4.65	0.489	0.109	4.42	4.88
	CSF-CIT	20	4.35	0.745	0.167	4.00	4.70
	CSF-SODIS	20	3.80	0.951	0.213	3.35	4.25
	CSF	20	4.15	0.875	0.196	3.74	4.56
	RW	20	2.65	1.461	0.327	1.97	3.33
	Total	100	3.92	1.169	0.117	3.69	4.15

Table 3: Organoleptic properties of the treated Omisanjana water samples

*Raw water (RWS), flocculated water (FRW), charcoal-Sand filtered water (CSF), solar disinfection (SODIS), charcoal-sand filtered-chlorinated water (CSF-CLO), charcoal-sand filtered-citrated water (CSF-CIT)

Organoleptic parameters	**Raw water**	**Solar**	**Sand/Charcoal**	**Citric acid**	**Chlorinated water**
Clarity	1.50^{a}	3.65^{bc}	3.55^{b}	4.10^{bc}	4.20^{bc}
Taste	1.50^{a}	3.35^{b}	3.40^{b}	4.10^{c}	4.30^{c}
Appearance	1.00^{a}	4.15^{b}	4.25^{b}	4.30^{b}	4.70^{c}
Odour	1.75^{a}	3.75^{b}	3.85^{b}	4.25^{c}	4.65^{d}
Overall acceptability	2.65^{a}	3.80^{b}	4.15^{bc}	4.35^{bc}	4.65^{c}

Table 4: Duncan Multiple Range Test (DMRT) of drinking quality treated water

- Letters in superscript indicate significant variation between the mean values of the test parameters

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