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Effect of Household Water Treatment on Microbiological Quality of Drinking Water in Rural Communities of Plateau State, Nigeria: A Comparative Study of Two Treatment Modalities

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Abstract

- ***Background:***

Dramatic improvement in the microbiological quality of household drinking water is known to occur with the use of simple, acceptable and affordable household water treatment technologies. This study aimed to compare the effect of combined flocculant-disinfectant on microbiological water quality with that of disinfectant alone in two rural communities of Plateau State.

- ***Methods:***

A quasi-experimental study was conducted in households of selected rural communities A and B among 102 and 100 adult female respondents respectively who were primary caregivers of under-fives. Data was collected at baseline using a semi-structured interviewer-administered questionnaire and stored drinking water was analyzed for microbial contamination. The intervention involved the use of combined flocculant-disinfectant in community A (intervention group) and the more familiar sodium hypochlorite solution in community B (control group) to treat drinking water for 12 weeks during which four weekly microbiological analysis of stored drinking water was done. The tools used at baseline were also used to collect post-intervention data. Data was analyzed using SPSS 23 and microbiological water quality was compared within and between groups, before and after intervention.

- ***Results:***

At baseline, 74.0% of households in intervention group and 61.5% in control group had poor microbiological water quality ($p = 0.079$) with comparable mean Escherichia coli concentrations of 31.62 $\pm$ 13.49 CFU/100ml and 19.95 $\pm$ 9.23 CFU/100ml respectively ($p = 0.060$). After intervention, combined flocculant-disinfectant was found to be effective in reducing the mean concentrations of E. coli and total coliforms to 1.55 $\pm$ 1.31 CFU/100ml ($p < 0.001$) and 1.35 $\pm$ 1.23 CFU/100ml ($p < 0.001$) respectively. When compared with sodium hypochlorite solution, which was also effective in reducing E. coli concentrations to 3.72 $\pm$ 1.19 CFU/100ml ($p < 0.001$) and total coliforms concentrations to 1.86 $\pm$ 1.41 CFU/100ml ($p < 0.001$), combined flocculant disinfectant was found to be more effective ($p < 0.001$). The use of flocculant-disinfectant was associated with much more reduction in turbidity of water ($p < 0.001$) and greater satisfaction among its users when compared to users of sodium hypochlorite ($p = 0.008$).

- ***Conclusion:***

Combined flocculant-disinfectant was found to be more effective in improving microbiological and physical qualities of household drinking water than disinfectant. Collaboration of Government with manufacturers and other stakeholders, should make this water treatment method more available to rural populations who have demonstrated acceptance and satisfaction with its use.

Keywords:- *Household water treatment, microbiological quality, rural communities.*

I. INTRODUCTION

Water is an essential compound necessary for the sustenance of life which should be safe, accessible and available in adequate quantities for everyone [1]. One of the most common health risks associated with drinking water is microbiological contamination which occurs either directly or indirectly, by human or animal faeces [2]. Making safe drinking water universally accessible and affordable for all persons is the cornerstone of preventing waterborne diseases in all populations and is an integral means of achieving sustainable development [3,4]. Populations in low-income countries, especially those living in the rural areas, are particularly at risk of waterborne diseases because they lack access to improved water sources and those who have some form of access still have to walk long distances to get water, thereby increasing the risk of contamination during transportation. Population growth in urban areas also presents a huge challenge in further increasing improved drinking water coverage [5,6]. In Nigeria, 34% of households (42% for rural households) lacked access to an improved water source in 2018 [7]. In Plateau State, 54% of households lacked access to an improved water source [7].

The risks of waterborne diseases and death have been shown to be reduced by the use of simple, acceptable and affordable technologies of water treatment at the household levels [8]. Household Water Treatment (HWT) technologies, also known as 'point-of-use' or 'point-of-entry' water treatment technologies are any of a range of devices or methods, which are employed for the purposes of treating water in the home or at the point of use in other settings. Despite the lack of access to improved water sources in most developing countries, the practice of HWT remains poor. Only 33% of households in these countries engage in HWT (36.6% for urban and 30.1% for rural dwellers) [9]. Appropriate methods of HWT are least practiced among the poorest households who are also the ones more at risk of water-borne diseases [9]. In Nigeria, an increasing number of households continue to drink water without any form of treatment (88% in 2013[10] and 90% in 2018 [7]) with only 3% of rural households engaging in an appropriate form of HWT. The situation is worse in rural areas who rely largely on ground and surface water for domestic purposes including drinking. This water may be highly turbid and prone to faecal contamination due to poor sanitation [9].

Certain HWT technologies have been identified as effective and suitable for rural and resource-limited settings based on selected technical characteristics and performance criteria [11]. The use of these simple HWT technologies has the potential to dramatically reduce the global burden of waterborne diseases [11,12]. One of such methods is chlorination of water which is the most widely practiced at the community level and in emergency situations. Apart from boiling, it is the most widely used in the home [13]. Chlorine-based disinfectants are usually available as sodium hypochlorite (such as household bleach), chlorinated lime, or high-test hypochlorite (chlorine tablets) and are the most popular commercial HWT products [13,14]. Sodium hypochlorite solution is also the most widely used chlorine disinfectant at the household level in Nigeria. It is safe for use by both adults and children [15]. In addition to controlling disease-causing organisms, chlorination reduces many disagreeable tastes and odours, eliminates slime bacteria, moulds and algae that commonly grow in water supply reservoirs and storage vessels and helps remove iron and manganese from raw water [16]. The added benefit of having a residual disinfectant effect that prevents microbial re-growth and protects treated water throughout the distribution or storage system makes it superior to boiling which is mostly used in households of resource-limited countries [16].

However, disinfection with chlorine alone has limitations against protozoa, particularly *Cryptosporidium parvum*, some viruses and pathogens hidden within flocs or particles. High levels of turbidity can protect microorganisms from the effects of disinfection, stimulate the growth of bacteria and increase significantly the chlorine demand [1]. The combination of flocculation and time-released disinfection is another method of water purification which is offered by flocculant–disinfectant powders, tablets or granules and are also safe, relatively affordable, acceptable and have been widely distributed in developing countries. The flocculant-disinfectants contain a chemical coagulant, such as an iron or aluminum salt, and a disinfectant, such as chlorine. They have been shown to have the capacity of reducing bacteria and viruses more than just chlorination and have the capacity of removing *Toxoplasma* and *Cryptosporidium parvum* oocysts from drinking water, a limitation of chlorination. They improve the turbidity of water after decanting and leave behind, a free chlorine residual that produces microbiologically safer water and are highly recommended for treatment of surface waters and some ground water sources due to high turbidity [17-19].

The burden exacted by waterborne in developing countries can be reduced when simple, appropriate and affordable HWT methods are made available to households since evidence has shown that populations are willing and able to pay for some or all of the cost of HWT products due to their relative affordability, especially when they are made to understand the importance of doing so [13,20]. The aim of this study is to determine the effect of HWT with flocculant-disinfectant on microbiological water quality and compare this effect with that of the relatively more familiar disinfectant, Sodium hypochlorite solution, in two rural communities of Plateau State, a part of the country where such effects have not yet been adequately documented.

II. MATERIALS AND METHODS

- **Study Area:** The study was carried out in Plateau State, Nigeria, which is divided into 3 senatorial zones and 17 Local Government Areas (LGAs). The rural areas of the state, having up to 69% of inhabitants, frequently reports cases of diarrhea and outbreaks of cholera especially among under-fives with a large proportion of households having coliforms present in their drinking water [21].

- **Study Design and population:** A community-based, quasi-experimental study involving two treatment groups was carried out among adult female primary care-givers of under-fives within two selected rural communities Plateau State. This is because females are more likely to be in charge of drinking water management in households and also because under-fives are highly susceptible to waterborne diseases. The intervention community A utilized combined flocculant-disinfectant powder as it its HWT method, while the control community B utilized sodium hypochlorite solution for HWT.

- **Sample size and sampling Technique:** A minimum sample size of 89 was calculated for each community. Multistage sampling technique was employed in selecting the participants per households. Two communities were selected from two wards and two LGAs all using simple random sampling technique (SRS) by balloting. Eventually, SRS was used to select Foda-Fobur community as the intervention community A and Igbak as control community B which were both studied as clusters. A total of 100 households/participants met the selection criteria in community A and 102 in community B.

- **Study instruments:** The study instruments included a pretested, semi- structured, interviewer administered questionnaire (included questions on socio-demographic characteristics, knowledge of household water treatment and water management practices) and laboratory instruments for water collection and analysis.

- **Data collection method:** Research assistants were recruited and trained for the study; advocacy visits and permission for the study were obtained from LGA chairmen and community heads; and written informed consent obtained from all participants.

At base line data was collected from participants using the questionnaire and drinking water samples were collected and analyzed.

For the intervention with the HWT products, participants in each group were given health education on water quality and contamination as well as the importance of HWT. They were then taught how to treat drinking water using the HWT products. Study participants in community A were taught how to use one sachet of flocculant-disinfectant powder to treat approximately 10 litres of water using the following steps [22]:

- First step: Fetch water into a bucket of 10 litres capacity.
- Second step: Empty the contents of one sachet into the bucket.
- Third step: Stir the water vigorously for 3-5 minutes and allowed to stand for another five minutes.
- Fourth step: When the water looks clear with sediments at the bottom, decant into another clean storage container.
- Fifth step: Allow water to stand covered in a water storage container for about 20 minutes for proper disinfection to take place before consumption.

The participants were also taught to discard the residue from this preparation in an area far from the reach of animals and children (preferably by a hill side or several meters away from residential areas). The treated water was to be consumed within 24 hours of treatment. If not, it was to be discarded and a fresh preparation made [17].

The participants in community B were taught to use the following steps when using sodium hypochlorite solution [23]:

- First step: Fetch water to fill the 20 litre bucket.
- Second step: Fill the cover cap of the sodium hypochlorite bottle and pour its solution into the bucket.
- Third step: Mix thoroughly until solution is completely mixed with the water.
- Fourth step: Wait 30 minutes after which water is now safe to drink.

For water that appeared very dirty, participants were advised to let the water settle before following these steps or alternatively, use two capfuls of sodium hypochlorite solution for the treatment of 20 litres of dirty water.

The HWT product and a water storage container (of 10 and 20 litres capacity for communities A and B respectively) were given to each participant to take home. The quantity of HWT product received depended on the amount of water consumed per household which was already noted from baseline data collection. Nevertheless, those who received sodium hypochlorite solution were given at least a bottle each while those who received flocculant-disinfectant powder were given at least 15 sachets each to last for 2 weeks before the next visit.

The two groups were followed for a period of 12 weeks. Research assistants visited households unannounced, every two weeks starting from the two weeks after initiation of intervention. During the two weekly visits, participants in community A were supplied with more sachets of flocculant-disinfectant and those in community B with more bottles of sodium hypochlorite solution based on the need. Stored drinking water samples were collected from each household every two weeks for determination of chlorine concentration, turbidity and pH, while collection of water samples for microbiological analysis was done every four weeks. The collection of water samples was done irrespective of the time of water treatment in the household. Compliance with intervention was determined at every visit by collecting and counting empty sachets of flocculant-disinfectant for the first group, by a drop in the level of solution which will be marked on the Water Guard bottle in the second group and most especially by detection of free residual chlorine in water samples for both groups.

Twelve weeks after the initiation of intervention, the questionnaire administered at baseline data collection was re-administered to all participants. Household stored drinking water samples were collected and analyzed microbiologically, also for pH, turbidity and chlorine concentration.

- **Laboratory analysis:** Household drinking water samples were collected by asking the respondents themselves to fetch from the storage containers. It was then poured into sterile plastic bottles and transported on icepacks arranged in a cooler to the NVRI Vom within 6-8 hours of collection for bacteriological analysis. The Agar Plate Count method for coliform count was used to detect coliforms, following incubation of samples at temperatures of 32-37ºC in Eosin Methylene-Blue (EMB) agar for 48 hours. The concentration of bacteria (in CFU/100mls) especially of *E. coli* was determined since its presence shows recent faecal contamination of water and also indicates whether other potentially harmful bacteria, viruses or parasites may be present in water [24]. The presence or absence of other bacteria isolates such as *Klebsiella sp., Proteus sp., Pseudomonas sp., Bacillus sp., Citrobacter sp.* and other isolates which could be present in the water samples were determined. Additional organisms such as yeast cells also grew on the medium as pin-point colonies. Physicochemical parameters such as turbidity, pH and residual chlorine concentration of water samples were also assessed.

- **Grading of microbiological quality of water:** Bacterial concentrations particularly of *E.coli* expressed in terms of Colony Forming Units (CFU) were used to determine the microbiological quality of water. The households within each community were classified as either having good microbiological water quality (*E.coli* concentrations <1 CFU/100 ml which is the WHO-recommended maximum for drinking water) or poor microbiological water quality (*E. coli* concentrations of ≥1 CFU/100 ml). The concentrations of total coliforms were also determined in the water samples just to give an insight to the general quality of water.

- **Statistical Analysis:** Data was processed and analyzed using the IBM Statistical Package for Social Sciences (SPSS) version 23. Data was summarized and presented using mean and standard deviation, tables, proportions and charts. The mean *E. coli* concentration of household drinking water for each community was calculated at baseline and at post intervention (by taking the average at 4, 8 and 12 weeks). Both paired and unpaired t-tests were used to compare means within and between the two communities respectively. Logarithm transformation was applied to data obtained for bacterial concentrations. The mean *E.coli* concentration of water samples collected from each household at the end of intervention was used to categorize the households in each community into having either good or poor microbiological water quality and both groups were compared using the Chi- square test (χ^2). All tests of significance were two-tailed. A 95% confidence level was used for the study and a p-value of less than or equal to 0.05 ($p \leq 0.05$) was considered statistically significant.

- **Ethical consideration:** Ethical approval for the research was obtained from the Human and Research Ethics Committee of Jos University Teaching Hospital. All participants gave both verbal and written informed consent before involvement in the study.

- **Limitation of the study:** This study could not be conducted for a longer period of time due to cost implications, hence long-term use and sustainability of these interventions could not be adequately assessed.

III. RESULTS

A. Household and respondent characteristics

Attrition rates of 1.9% and 4% were observed in communities A and B respectively. The mean age of the respondents were 34.0 ± 12.9 years and 31.0 ± 11.6 years in communities A and B respectively.

Table 1 showed that the household and personal characteristics of participants in both communities were largely similar making them comparable. Both communities also had over 60% of respondents with good knowledge of water contamination and HWT.

Characteristics	Community A (n = 102) Freq	%	Community B (n = 100) Freq	%	χ^2	df	P-value
Age group (years)							
≤ 40	76	76.0	78	81.3			
> 40	24	24.0	18	18.7	0.802	1	0.371
Marital status							
Currently married	84	82.4	91	91.0			
Not currently married	18	17.6	9	9.0	3.244	1	0.072
Ethnicity							
Indigenous tribes	82	80.4	90	90.0			
Non indigenous tribes	20	19.6	10	10.0	3.686	1	0.239
Level of education							
No formal education	16	15.7	10	10.0			
Primary	39	38.2	52	52.0	6.346	3	0.096
Secondary	38	37.3	35	35.0			
Tertiary	9	8.8	3	3.0			
Employment status							
Employed[#]	73	73.0	82	85.4			
Not employed[##]	27	27.0	14	14.6	4.565	1	0.033

Household monthly income (Naira)							
<5000	10	9.8	14	14.0			
5000 – 20000	58	56.9	56	56.0	1.302	3	0.729
21000 – 50000	25	24.5	24	24.0			
≥51000	9	6.9	6	6.0			
Household size							
1 -5 persons	50	50.0	36	39.0			
≥ 6 persons	50	50.0	60	61.0	3.108	1	0.078
Knowledge of water contamination and HWT							
Good	65 (63.7)		71 (71.0)				
Fair	36 (35.3)		27 (27.0)		-	-	0.416*
Poor	1 (1.0)		2 (2.0)				

*= Fisher's exact
= Farming, petty trading, artisan
= Housewife, student, applicant

Table 1:- Baseline socio-demographic characteristics of caregivers and household

B. Microbiological quality of drinking water

➢ *Microbiological quality of drinking water at baseline*

Table 2 shows that the baseline proportion of households with water contaminated by *E. coli* and total coliforms in community was 74% and 78% respectively while for community B, it was 61.5% and 80.2% respectively. These showed no statistically significant difference (p = 0.060 and p = 0.704 respectively).

Group of bacteria	Community A (n = 100) Freq (%)	Community B (n = 96) Freq (%)	χ^2	df	p-value
E. coli (faecal contamination)					
Present	74 (74.0)	59 (61.5)			
Absent	26 (26.0)	37 (38.5)	3.52	1	0.060
Total coliforms (Colifrom contamination)					
Present	78 (78.0)	77 (80.2)			
Absent	22 (22.0)	19 (19.8)	0.14	1	0.704

Table 2:- Households with bacterial contamination of water at baseline

➢ *Effect of water treatment with combined flocculant-disinfectant and sodium hypochlorite on the microbiological quality of water (within group comparisons)*

The mean *E.coli* and total coliform concentrations of drinking water samples before intervention with both flocculant-disinfectant and sodium hypochlorite showed statistical significant reductions after intervention in communities A and B respectively as depicted in table 3 (p < 0.001).

Bacteria type	Before intervention Mean ± Std	After intervention Mean ± Std	T_{paired}	df	p - value
Community A (flocculant-disinfectant group)					
Mean *E. coli* Concentration (CFU/100mls)	31.62 ± 13.49	1.55 ± 1.31			
Mean Log concentration of *E. coli*	1.50 ± 1.13	0.19 ± 0.12	9.15	99	**< 0.001***
Mean Total Coliform Concentration (CFU/100mls)	346.74 ± 37.90	1.35 ± 1.23			
Mean Log concentration of coliforms	2.54 ± 1.59	0.13 ± 0.09	15.01	99	**< 0.001***

Community B (sodium hypochlorite group)					
Mean *E. coli* Concentration (CFU/100mls)	19.95 ± 9.23	3.72 ± 1.19			
Mean Log concentration of *E. coli*	1.30 ± 1.01	0.57 ± 0.34	4.35	95	**<0.001***
Mean Total Coliform Concentration (CFU/100mls)	549.54 ± 32.88	1.86 ± 1.41			
Mean Log concentration of coliforms	2.74 ± 1.53	0.27 ± 0.15	16.26	95	**<0.001***

*= significant

Table 3:- Comparison of mean E.coli and total coliform concentrations of drinking water within groups

Table 4 shows that more households had good microbiological water quality at post-intervention compared to pre-intervention in both communities. There was also a significant decrease in proportion of households with total coliform contamination from pre- to post-intervention.

Bacterial contamination	**Before intervention (n = 100)**	**After intervention (n = 100)**	χ^2	**df**	**p - value**
Community A (flocculant-disinfectant group)					
E. coli					
Feacally contaminated (poor quality)	74 (74.0)	12 (12.0)			
Not faecally contaminated (good quality)	26 (26.0)	88 (88.0)	78.417	1	**<0.001***
Total coliforms					
Contaminated with total Coliforms	78 (78.0)	20 (20.0)			
Not contaminated with total Coliforms	22 (22.0)	80 (80.0)	63.307	1	**<0.001***
Community B (sodium hypochlorite group)					
E. coli					
Feacally contaminated (poor quality)	59 (61.5)	32 (33.3)			
Not faecally contaminated (good quality)	37 (38.5)	64 (66.7)	15.229	1	**<0.001***
Total coliforms					
Contaminated with total Coliforms	77 (80.2)	44 (45.8)			
Not contaminated with total Coliforms	19 (19.8)	52 (54.2)	24.338	1	**<0.001***

*= significant

Table 4:- Comparison of household drinking water contamination within groups

➢ *Comparison of microbiological quality of water after intervention (between group comparisons)*

There were no statistical significant differences in means of *E.coli* and total coliform concentrations between the two groups at baseline (table 2). At post-intervention however, the difference in mean *E.coli* concentrations and in mean total coliform concentrations between the communities were found to be statistically significant with community A having the lower of both mean values (table 5).

Mean Values	After intervention	
	Community A (n = 100) Mean ± std	**Community B (n = 96) Mean ± std**
Mean *E. coli* Concentration (CFU/100mls)	1.55 ± 0.31	3.72 ± 1.19
Mean Log concentration of *E. coli*	0.19 ± 0.12	0.57 ± 0.34
	$T_{unpired}$ = 3.27; df = 194; **p = 0.001***	
Mean total coliform concentration (CFU/100mls)	1.35 ± 1.23	1.86 ± 1.41
Mean Log concentration of total coliforms	0.13 ± 0.09	0.27 ± 0.15
	$T_{unpaired}$ = 3.84; df = 194; **p < 0.001***	

* = significant

Table 5:- Comparison of mean bacterial concentrations between the two communities

After intervention, fewer households in community A had both faecal and total coliform contamination compared to households in community B (table 6).

Bacteria	After intervention	
	Community A Freq (%)	**Community B Freq (%)**
E. coli Not faecally Contaminated	88 (88.0)	64 (66.7)
Feacally contaminated	12 (12.0)	32 (33.3)
	χ^2 = 12.80; df = 1; **p < 0.001***	
Total coliform Not contaminated	80 (80.0)	52 (54.2)
Contaminated	20 (20.0)	44 (45.8)
	χ^2 = 14.86; df = 1; **p < 0.001***	

* = significant

Table 6:- Comparison of drinking water contamination of households between communities

At pre-intervention, *Klebsiella sp.* was the most commonly occurring of all the other bacterial isolates in drinking water samples of both communities A and B (62.0% and 72.9% respectively). All bacterial isolates were similar across the two communities except for *Citrobacter sp.* which was totally absent in B and *Proteus sp.* which was totally absent in A. After intervention, more drinking water samples in community B were contaminated with *Klebsiella sp.*, *Baccilus sp.*, *Proteus sp.* and yeast cells compared to community A (Table 7).

Bacteria isolates	Before intervention				After intervention			
	Community A (n = 100) Freq(%)	CommunityB (n = 96) Freq (%)	χ^2	P-value	Community A (n = 100) Freq (%)	CommunityB (n = 96) Freq (%)	χ^2	P-value
Klebsiella sp.	62 (62.0)	70 (72.9)	2.65	0.103	13 (13.0)	34 (35.4)	13.5	**<0.001***
Pseudomonas sp.	22 (22.0)	25 (26.0)	0.33	0.564	10 (10.0)	18 (18.8)	3.06	0.081
Citrobacter sp.	9 (9.0)	0 (0.0)	9.24	**0.002***	2 (2.0)	0 (0.0)	1.94	0.164
Bacillus sp.	13 (13.0)	23 (24.0)	3.92	**0.048***	0 (0.0)	9 (9.4)	9.83	**0.002***
Proteus sp.	0 (0.0)	18 (18.8)	20.04	**<0.001***	0 (0.0)	8 (8.3)	3.94	**0.046***
NLF	11 (11.0)	4 (4.2)	3.36	0.060	3 (3.0)	4 (4.2)	0.03	0.953
Other isolates[#]	7 (7.0)	8 (8.3)	0.10	0.758	2 (3.0)	3 (3.1)	2.41	0.120
Yeast cells	11 (11.0)	11 (11.5)	0.01	0.941	2 (2.0)	9 (9.4)	5.03	**0.025***

Key: NLF = Non Lactose Fermenters; Multiple responses allowed
*= Significant; [#]=*Aeromonas hydrophila, Staphylococcus sp*

Table 7:- Comparison of other bacterial isolates present in water between groups before and after intervention

C. Physico-chemical water properties

Table 8 shows that at pre- and post-intervention, mean pH and residual chlorine concentrations were similar across groups. Although there was statistically significant difference in mean turbidity of water samples at pre-intervention as that of community B was lower than community A (p = 0.042), the mean turbidity of community A was found to be much lower than that of B at post-intervention (p < 0.001).

	Before intervention				After intervention			
	Group A (Mean ± Std)	Group B (Mean ± Std)	T-test	P-value	Group A (Mean ± Std)	Group B (Mean ± Std)	T-test	P-value
pH	6.70 ± 0.69	6.65 ± 0.30	0.66	0.507	6.94 ± 0.10	6.90 ± 0.22	1.47	0.145
Turbidity (NTU)	5.59 ± 2.90	4.83 ± 2.30	2.05	**0.042***	1.69 ± 0.62	3.29 ± 0.77	22.30	**<0.001***
Residual chlorine (mg/dl)	0.05 ± 0.02	0.04 ± 0.02	1.78	0.078	0.30 ±0.04	0.29 ± 0.09	0.17	0.864

*****= significant

Table 8:- Comparison of physico-chemical properties of water between groups

Two weekly determination of drinking water turbidity during the intervention period showed that mean turbidity levels ranged from 1.22 to 2.12 NTU in community A with the lowest mean turbidity observed at week 12. In community B, mean turbidity ranged from 3.55 to 4.12 NTU with the 10^{th} week having the lowest (fig. 1).

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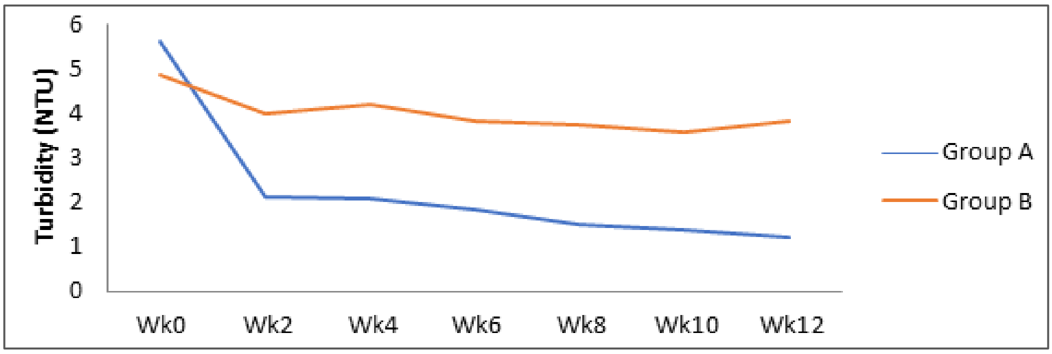

Key: Wk = Week

Fig 1:- Trend in mean turbidity of drinking water samples during the period of intervention

The proportion of households in A that had optimal residual chlorine levels of 0.20 – 0.50 mg/dl in drinking water samples ranged from 74.9% to 96.0% (with an average of 90.8%) which peaked at the 12th week as depicted in fig. 2. In B, it ranged from 65.0% to 90.7% (with an average of 81.5%) and peaked in the 10th week of intervention.

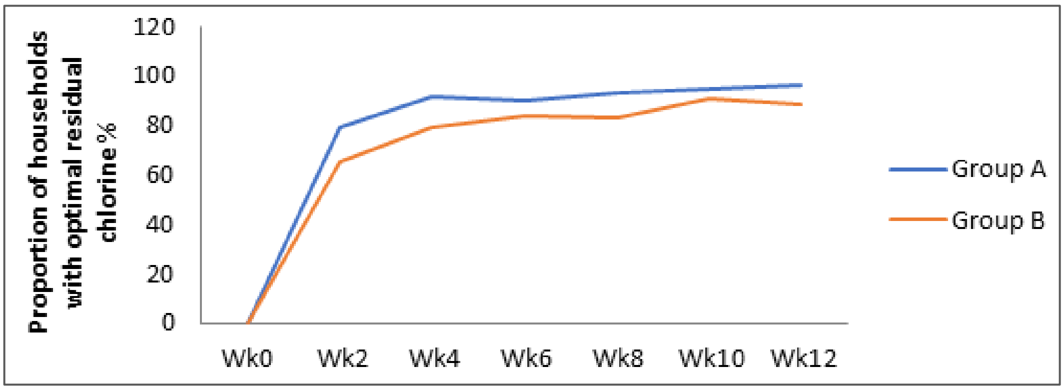

Fig 2:- Trend in proportion of households with optimal residual chlorine levels in drinking water

D. Satisfaction with drinking water quality

As shown in table 9, respondents in community B had higher levels of satisfaction with drinking water quality before intervention than respondents in community A ($p = 0.008$). After intervention, the level of satisfaction was found to be higher among respondents in community A compared to B.

At baseline, more respondents in community B (85.4%) perceived that their water was safe to drink without treatment compared to 57.9% of respondents in community A ($p < 0.001$). Among these respondents in community B, 62.2% felt this was because the water appeared clean compared 40.4% of respondents in A who felt the same way ($p =0.017$). Among the respondents who did not think their water was safe to drink without treatment, 65.1% in A thought it was because the water appeared dirty or had may impurities compared to 28.6% respondents in B who felt the same way ($p = 0.017$).

After intervention, most respondents in both communities felt their water was not safe without treatment. Out of these, 96.8% of respondents in community A compared to 15.5% of respondents in group B felt the water was not safe without treatment because it appeared dirty and had many impurities ($p < 0.001$); while 59.5% of respondents in community B compared to 25.3% in A thought it was because the water sources were always open with so many users ($p < 0.001$)

Responses	Before intervention				After intervention			
	community A (n =100) Freq %	**community B (n = 96) Freq %**	χ^2	**p-value**	**community A (n =100) Freq %**	**community B (n = 96) Freq %**	χ^2	**p-value**
Satisfaction with water quality								
Very satisfied	32 (32.0)	40 (41.7)			98 (98.0)	85 (88.5)		
Satisfied	44 (44.0)	52 (54.2)	-	**0.008***	2 (2.0)	11 (11.5)	7.04	**0.008***
Indifferent	6 (6.0)	0 (0.0)			-	-		
Unsatisfied	17 (17.0)	4 (4.1)			-	-		
Very unsatisfied	1 (1.0)	0 (0.0)			-	-		

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Perception of water quality/safety without treatment								
Safe to drink	57 (57.9)	82 (85.4)			5 (5.0)	12 (12.5)		
Not safe to drink	43 (42.1)	14 (14.6)	19.18	**<0.001**	95 (95.0)	84 (87.5)	3.43	0.063
Reasons for the perception of safety**								
It appears clean	23 (40.4)	51 (62.2)	5.74	**0.017***	1 (20.0)	7 (58.3)	1.96	0.162
Smells/tastes good	3 (5.2)	9 (11.0)	1.32	0.250	2 (40.0)	1 (8.3)	2.29	0.130
Generally known to be clean	14 (24.6)	34 (42.7)	3.92	**0.048***	1 (20.0)	2 (16.7)	0.03	0.873
Properly covered	11 (19.3)	7 (8.5)	3.53	0.060	1 (20.0)	2 (16.7)	0.03	0.873
We hardly fall ill	2 (3.5)	3 (3.7)	0.01	0.975	0 (0.0)	1 (8.3)	0.42	0.519
Other reasons	2 (3.5)	9 (11.0)	2.48	0.115	-	-		
Reasons for the perception of non-safety**								
Appears dirty/so many impurities	28 (65.1)	4 (28.6)	5.69	**0.017***	92 (96.8)	13 (15.5)	121.0	**<0.001***
Smells/tastes bad	20 (46.5)	8 (57.1)	1.56	0.210	18 (18.9)	10 (11.9)	2.29	0.130
Generally known to be unclean	2 (4.7)	1 (7.1)	0.16	0.686	2 (2.1)	2 (2.4)	0.02	0.901
May be contaminated	5 (11.6)	1 (7.1)	0.02	0.890	48 (50.5)	51 (60.7)	1.86	0.172
Always open/too many users	6 (14.0)	1 (7.1)	0.11	0.746	24 (25.3)	50 (59.5)	21.46	**<0.001***

*= significant
****=**Multiple responses allowed

Table 9:- Respondents' satisfaction with drinking water quality before and after intervention

IV. DISCUSSION

For both groups, the respondents' socio-demographic and household characteristics were largely similar which gave a good basis for comparison. On the average, household drinking water samples were highly contaminated at baseline with mean *E. coli* and mean total coliform concentrations exceeding far beyond WHO recommended values. These are comparable to findings from studies conducted in rural areas of Kano [25] and Plateau [26] States in which mean total coliform concentration of household drinking water were found to be 44.96 $\pm$ 53.04 CFU/100ml and 12.5 $\pm$ 22.8 CFU/100ml respectively. Over half of the households in both communities had poor microbiological quality of drinking water (demonstrated as *E.* coli/faecal contamination) as well as total coliform contamination of water at baseline. Several other studies in developing countries, especially in rural communities, have shown high levels of *E. coli* and total coliform contamination of household drinking water. Two studies done in Kano State Nigeria, showed that 83.0% and 94.1% of household water samples were contaminated with coliform bacteria respectively [25,27]. Another study done in a Niger Delta region of Nigeria had 67.9% of samples contaminated with *E. coli* [28], while a study in Ghana showed that 83.0% of water samples were also contaminated with *E. coli* [29]. Other studies have shown that less than half of household drinking water samples were contamination with indicator organisms in rural communities of Plateau State [26] and Niger Delta region [30] of Nigeria. The variations in contamination levels as shown in these studies could be as a result of factors such as season of the year the study was conducted, location of study area such as riverine area, differences in laboratory techniques and procedures.

Apart from *E. coli*, other coliforms or enterobacteria isolated from drinking water samples include Klebsiella, proteus, citrobacter, non-lactose fermenting bacteria (such as proteus, pseudomonas, Salmonella and Shigella) were isolated from the water samples. These are the organisms that have frequently been isolated from household drinking water samples in other studies [25,26,31]. Some may not necessarily be pathogenic but a few have been known to cause diseases in immuno-compromised persons and children.

This study has demonstrated statistically significant improvement in microbiological quality of household drinking water after intervention with the combined flocculant-disinfectant as shown by significant reductions in mean *E. coli* and mean total coliform concentrations and reductions in proportion of households with feacal and total coliform contaminated drinking water when compared to baseline values. This same effect has been demonstrated on both source and household water samples in studies conducted in Nigeria [32] and Guatemala [17]. Improvement in water quality with flocculant-disinfectant use could be attributed to the potency of the product itself, proper use of the method as a result health education re-enforcement and consistent use as demonstrated by presence of residual chlorine in water samples. The use of disinfectant alone in form of sodium hypochlorite solution also showed significant improvement in water quality just as it was demonstrated in studies employing the use of disinfection with chlorine-based products in India [33], Indonesia [34], Nigeria and other developing countries [35]. Many of these studies employing the use of disinfectant or combined flocculant-disinfectant also went further to demonstrate reduction in burden of diarrheoa as a result of improvement in water quality.

When compared to sodium hypochlorite solution, this study showed that combined flocculant-disinfectant was more effective in removing both feacal and total coliforms as well as other isolates such as *Klebsiella sp., Pseudomonas sp., Bacillus sp.* and yeast cells. Similar effects were demonstrated in studies conducted in Kenya [36,37]. Flocculant-disinfectant was also found to be more effective in removing coliforms and yeast cells than sodium hypochlorite disinfectant in rural areas of Kwara State [32]. All these studies similarly demonstrated significant reduction in turbidity of the drinking water samples which could have contributed to the significant greater improvement in microbiological quality. On the other hand, sodium hypochlorite was found to have a greater effect in improving microbiological water quality than flocculant-disinfectant in a Bangladesh [20]. This difference could have resulted from the higher rate of utilization of sodium hypochlorite compared to flocculant-disinfectant in the study.

The mean drinking water turbidity of community A households was significantly lower than that of B and their mean pH values which were comparable, were within the acceptable range of 6.5 – 8.5 necessary for chemical disinfection. Turbid waters have been found to contain pathogens attached to suspended particles which are relatively resistant to disinfection. Technologies that reduce turbidity as well as disinfect are ideal for such settings. This could have contributed to the greater effect of flocculant-disinfectant over sodium hypochlorite solution in reducing microbial contamination since it significantly lowered turbidity more than sodium hypochlorite. In developing countries where numerous persons rely on turbid water for drinking, the use of sodium hypochlorite solution at standard doses may not be as effective in controlling water-borne diseases as combination systems employing flocculation and disinfection. This has also been demonstrated in rural Kenya [37].

Free residual chlorine measured in water samples during unannounced visits showed that the products were actually being utilized in both groups since optimum chlorine levels of greater than 0.2mg/l were detected in an average of 90.8% of households in community A and 81.5% of households in community B during the intervention period. The high uptake of the interventions could have been influenced by the initial training of respondents, follow-up health education sessions and involvement of community members in the intervention. Household drinking water samples that had free residual chlorine levels less than the optimum value may have resulted from storage of water for longer than 1-2 days. Finding from Guatemala [17] and Liberia [38] also showed that after measuring for free chlorine in water samples, 85% of households in both studies consistently used flocculant-disinfectant throughout the intervention period with the least use observed at the initial part of intervention.

Satisfaction with drinking water quality among respondents in both groups was better after intervention than before intervention. It was lower before intervention and higher after intervention among community A respondents when compared to community B respondents because the drinking water of community A households appeared dirtier than that of community B at baseline and also probably because of the visible effect of water clarity produced by the use of flocculant-disinfectant. The interventions were generally accepted in both communities. Satisfaction with the use of flocculant-disinfectant and sodium hypochlorite has also been demonstrated in studies conducted in Kenya [36], Liberia [38] and Guatemala [17].

V. CONCLUSION

This study has demonstrated that a significant number of households in both groups had drinking water that were highly contaminated at baseline. The treatment of water with both combined flocculant-disinfectant and disinfectant alone were found to significantly improve the microbiological quality of drinking water. However, flocculant disinfectant was found to be more effective in improving microbiological water quality and in reducing turbidity. At the end of the study, the participants were satisfied with the quality of their water and treatment methods but this was observed more among users of flocculant-disinfectant than among users of sodium hypochlorite.

RECOMMENDATIONS

There is need to make available these simple, affordable and effective HWT technologies of flocculant-disinfectants and sodium hypochlorite to rural communities who have shown satisfaction with their use. Flocculant-disinfectant will be most effective and appreciated in areas with turbid water. Awareness for these HWT methods can be carried out by conducting health education campaigns in rural areas through regular community outreaches, women group discussions and other relevant channels. The awareness creation and access to the HWT methods can be championed by Government in collaboration with manufacturers of these technologies, Public Health Physicians, community-based trained volunteers and other organizations.

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