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Performance of Household Water Treatment Methods for Microbial Removal under Household Conditions in Kabale District, Uganda

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Abstract

Despite the Ugandan government efforts to improve access to safe water sources, the rate at which diseases spread as a result of unsafe drinking water is absolutely high. The purpose the study was to assess the performance of household water treatment methods (HWT) and evaluate their ability to improve the microbial quality of drinking water under household conditions in Kabale District. We randomly selected 205 households, where we collected treated and untreated water samples. We analyzed 46 paired samples (untreated and treated) of drinking water from 46 households that reported treated water available. Samples were analyzed for total coliforms and *Escherichia coli*, the major indicators of biological contamination of drinking water, to measure effectiveness of treatment under household conditions. All reported HWT did not significantly improve the microbial quality of drinking water. Mean $\log_{10}$ total coliforms removal were 0.7 $\log_{10}$ (40.1%) for boiling method, 0.2 $\log_{10}$ (23.7%) for biosand filtration method, -0.01$\log_{10}$ (-18.1%) for let it stand and settle method and 0.1 $\log_{10}$ (16%) for application of aqua safe tablets. In addition, mean log10 *Escherichia coli* removal were 0.7 $\log_{10}$ (-22.6) for boiling method, 0.3$\log_{10}$ (37.5%) for biosand filtration method, -0.4 $\log_{10}$ (-200%) for let it stand and settle method and 0.6 $\log_{10}$ (50%) for application of aqua safe. The microbiological quality of stored treated drinking water was significantly low. The government should sensitize the local people on safe storage of drinking water.

Keywords: Household water treatment; Water quality; Microbial removal

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Introduction

Approximately more than 700 million people globally lack access to improved water sources (WHO/UNICEF, 2015). Sub-Saharan Africa is most remarkably and disproportionately affected by lack of access to safe drinking water (WHO, 2010). There are approximately 327 million people without access to safe drinking water globally, who live in Sub-Saharan Africa (WHO, UNICEF. 2010, WHO, UNICEF. 2014). Therefore, one of the most important prerequisites for improving access to drinking water in developing countries is through implementation of household water treatment in communities that are in dire need of safe drinking water.

In Uganda, the governments' commitment to improve access to safe water sources is evidenced by the marked increase in the number of people with access to safe water sources from 54% in 2001 to 76% in 2015 WHO/UNICEF, 2015. However, the rate at which diseases spread as a result of unsafe drinking water is absolutely high. The study by UBOS & ICF, 2011 reported that 23%, and 14% of 1,096 children under the age five countrywide and in southwestern part of the country respectively, had diarrhea disease before 2012 demographic health survey. Additionally the study further revealed that child mortality rate was 90 deaths per

1,000 live births. Most of these deaths were caused by diarrheal disease as a result of unsafe drinking water. Diarrheal outbreaks may be associated with the consumption of contaminated drinking water and unhygienic household practices (Mattioli, M.C., et al. 2014). Evidence-based on research suggests that HWT methods have the ability to improve microbial quality of drinking water and can reduce the risk of disease outbreak as a result of drinking contaminated water (Clasen, T., et al. 2006). In the most recent study by (Wolf, J., et al, 2014) found out that respondents relying on unimproved water supplies, household based chlorination combined with safe storage vessels was associated with a 36% (95% CI: 28 – 45%) reduction in the risk of diarrhea. Although some studies indicate that HWT methods have the potential to reduce the risk of diseases that spread as result of drinking contaminated water, little work had been done to establish different HWT methods and their microbial removal efficiency in Kabale District, western Uganda. Therefore, the documentation of HWT and their effectiveness for microbial removal under household conditions in Kabale District was necessary.

Material and Methods

Study area characteristics

Kabale District is geographically located in Southwestern Uganda. it lies between 29° 45′ 0′′ E and 30° 15′ 0′′ E and latitudes 0° 1′ 0′′ S and 1° 29′ 0′′ S (Figure 1). It covers a total area of about 1,864 Square kilometers (KDLG, 2012). It borders with the districts of Kisoro to the West, Rukungiri to the North, Ntungamo to the East and the Republic of Rwanda to the South [KDLG, 2012.]. Approximately 81% of households have access to safe drinking water sources (KDLG, 2010). The main water sources of drinking water are public-stand pipes and protected spring technologies. Rainwater harvesting is practiced though on small scale (KDLG, 2010). The study assessed the performance of household water treatment methods in reducing the total coliforms and *Escherichia coli* in drinking water in the study area during unannounced household visits. The map of the study area is as presented in (Figure 1).

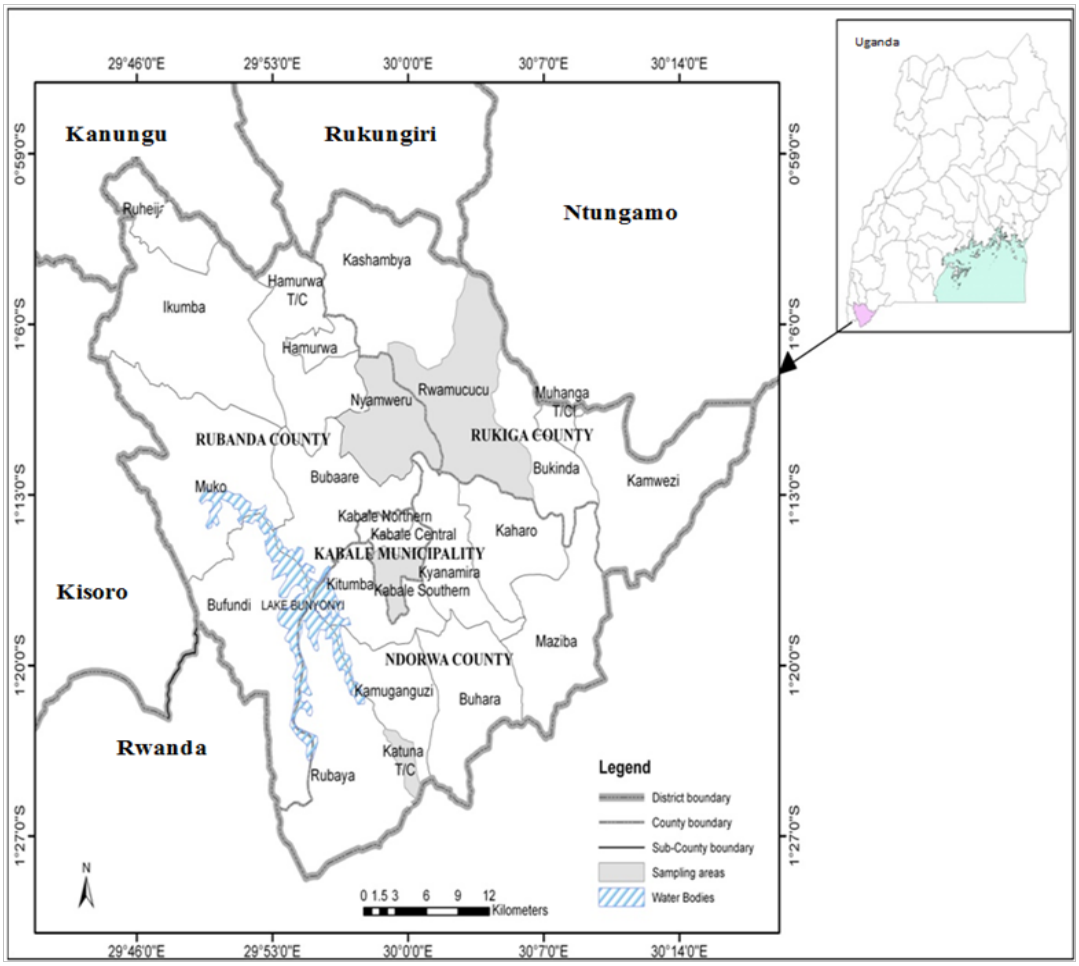

Figure 1: Map showing the study area (Kabale District) in southwestern Uganda.

Selection of participating households

The formula developed by Israel(1992) was used to quantify the minimum sample size because it yields a good sample size necessary for impact evaluations (Equations 1 and 2).

$n = N / (1 + N(e)^2)$ ---------- Equation: (1)

Where:
n = required sample size, N = Population size (119,631) and e = level of precision (7% equivalent to its standard value 0.07). Substituting in equation 1 gives the following sample size;

$n = (119,631) / (1 + 119,631 (0.07)^2) = 204$ ----------Equation: 2

Since 204 households were the minimum sample, we decided to randomly select 205 households and conducted interviews on sources of drinking water, household water treatment, and storage options.

Water sampling

For each household visited, both treated and untreated household water samples (if the household head reported them available) were collected aseptically in sterilized 500 ml bottles during unannounced visits. For purposes of quality, samples were collected in duplicates. The bottle corks were shielded with aluminum foil to avoid any form of hand contamination. We assigned identification numbers to each water sample and recorded the time of sampling, type of the sample (whether treated or untreated) and method used to treat it. The number of days the treated water had stayed up to sampling time was recorded. We transported the samples to NWSC-Kabale area water laboratory and stored at 4°C before they were analyzed.

Sample processing and analyses

We enumerated total coliforms and *Escherichia coli* using the membrane filtration method followed by incubation on hichrome media. Using this method, 100ml of water were aseptically drawn from each unit of the samples and filtered through a 0.45 µm millipore filter membrane. The membrane was aseptically removed from the filtration unit by using sterile forceps and placed on the medium in the petri-dish in a rolling motion to avoid entrapment of air. Total coliforms and Escherichia coli counts were determined by incubating the membrane filter on Hichrome media at 37°C and 44°C for 24 hours respectively.

To assess microbial removal efficiency of the HWT, we compared the concentrations of total coliforms and *Escherichia coli* before and after treatment by HWT in the laboratory. The enumeration of total coliforms and *Escherichia coli* before and after treatment was done following standard methods for the examination of water and wastewater(WE Federation, 2005, Rice, E.W., et al, 2012).

Log_{10} bacterial reductions were calculated using the equation below and were converted to percentage reduction. The formula for calculating bacteria removal efficiency is shown in equations 1− 2(Martin, H., 2010).

$$LR = Log_{10}(B.C_b) - log_{10}(B.C_a) \quad (1)$$

$$PLR = \frac{(B.C_b - B.C_a)}{(B.C_b)} \times 100\% \quad (2)$$

Where: LR = log reduction, PLR = percentage log reduction, $B.C_b$ = bacteria count before treatment, $B.C_a$ = bacteria count after treatment.

Results

We randomly interviewed 205 respondents of which, 81.5% were females and 18.5% were males. Only 46 respondents reported treated water available. Thus we were able to collect 46 paired samples, which we analyzed for total coliforms and *Escherichia coli.*

Sources of household drinking water

The field study survey revealed that 61.5% of respondents get their drinking water from water springs, 19% from public taps, 4.4% from private taps, 8.8% from neighbors' taps, 1.5% from shallow wells and 0.5% from boreholes (Table 1). Taps and boreholes were both privately and publicly owned. Water springs were publically owned. Shallow wells were constructed by local people faced with limited access to safe drinking water**.**

Table1: Reported sources of household drinking water.

Drinking water source	Frequency	Percent
Private tap	9	4.4
Shallow well	3	1.5
Public tap	39	19
Borehole	1	0.5
Water spring	126	61.5
More than one source	9	4.4
Piped water from the neighbour	18	8.8
Total	205	100

Reported household water treatment methods

The study findings revealed that majority respondents were using any one of the following HWT: boiling, biosand filtration let it stand and settle method, application of Water guard tablets and application of aqua safe tablets. 24.4% were not using any HWT to purify their drinking water (Table 2). Of all HWT reported, boiling was noted the most common method of household water treatment both in rural and urban areas, and was used by both educated and uneducated people in the study area. Let it stand and settle is common in rural areas, practiced by people with low education level and the elderly. Biosand filtration method is the latest of all HWT, however; its uptake was considerably low since its inception. A reasonable number of respondents (24.4%) were not practicing water treatment because of different reasons as indicated in (Table 3).

Table 2: Household water treatment technologies

HWT	Frequency	Percent	Valid Percent
Boiling	138	67.3	67.3
Add aqua safe tablets	2	1	1
Let it stand and settle	9	4.4	4.4
Biosand filtration	5	2.4	2.4
Water guard tablets	3	1.5	1.5
Don't use any HWT	50	24.4	24.4
Total	205	100	100

Table 3: Reasons for not treating household drinking water

	Frequency	Percent	Valid Percent
It is expensive	4	2	2
Bad taste and smell of treated water	13	6.3	6.4
I believe water is safe from the source	16	7.8	7.8
We are used to drinking untreated water	12	5.9	5.9
Time consuming	2	1	1
Not applicable	155	75.6	76
Others	2	1	1
Very old and don't have the energy to treat water	1	0.5	0.5
Total	205	100	100

Reported household water storage options

Majority respondents (33.7%) were using 5-litre jerricans as they their preferred household water storage option, whereas the small proportion of respondents (2.5%) were using clay pots (Table 4).

Table 4: Household water storage options.

Reported water storage options	Frequency	Percent	Valid percent
5-litre jerricans	69	33.7	33.7
Plastic buckets	28	13.7	13.7
20-litre jerricans	27	13.2	13.2
Jugs	16	7.8	7.8
Plastic bottles	6	2.9	2.9
Clay pot	5	2.5	2.5
Don't store drinking water	53	25.9	25.9
Total	205	100.0	100.0

Bacteriological quality of untreated water samples

(Figure 2) shows the concentration of total coliforms and *Escherichia coli* in untreated household test water samples in comparison with WHO and Uganda National Bureau of Standards (UNBS). Total coliforms ranged from 0 to 496 CFU/100 ml whereas *Escherichia coli* ranged from 0 to 242 CFU/100 ml. Table 5 illustrates the frequencies and percentages of household untreated test water samples falling under different risk categories; 0 CFU/100 ml (no risk/ in compliance), 1 to 10 CFU/100 ml (low risk), 11 to 100 (medium risk), 101 to 1000 (high risk) and < 1000 CFU/100 ml (Very high risk). It was revealed that only 6.5% of untreated test water samples were free of total coliforms (0 CFU/100 ml), whereas 52.2% fell within high risk category (101 to 1000). The study further revealed that 26.1% test water samples were free of *Escherichia coli,* whereas a small proportion of test water samples (4.3%) fell within high risk (101 to 1000).

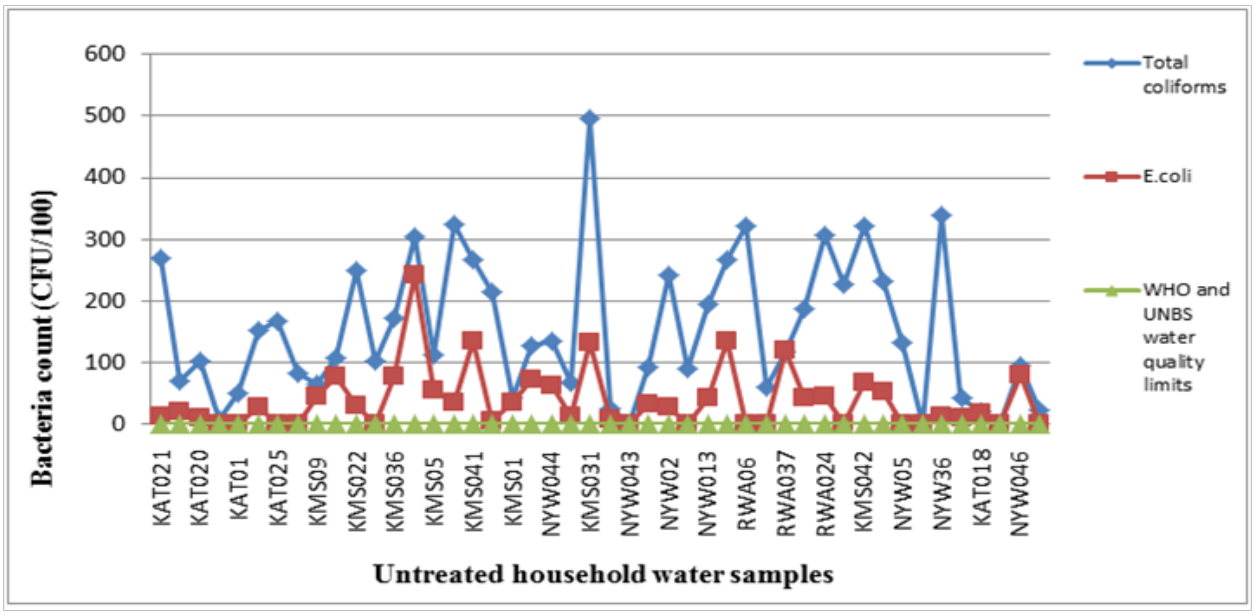

Table 5: Classification of total coliforms and *Escherichia coli* in household treated water samples.

Risk level category		Total coliforms		Escherichia coli	
		Frequency	Percent	Frequency	Percent
	No Detection (ND)	3	6.5	12	26.1
	1 – 10	2	4.3	10	21.7
	11 – 100	17	37.0	22	47.8
	101 – 1000	24	52.2	2	4.3
	Total	46	100.0	46	100

Performance of reported HWT

In this study, the efficiency of HWT (boiling, biosand filtration, Water guard tablets, aqua safe tablets and let it stand and settle) in removing total coliforms and *Escherichia coli* from water was determined under household and laboratory conditions as indicated in the subsequent subsections;

In boiled water samples, $\log_{10}$ total coliforms reduction ranged from -0.5 $\log_{10}$ to 2.4 $\log_{10}$, which corresponded with -115.6% to 99.6% removal efficiency (Table 7 and Table 8). Log_{10} *Escherichia coli* ranged from -0.4 $\log_{10}$ to 2.0 $\log_{10}$ which corresponded with -200% to 100% removal efficiency (Table 6). The overall mean $\log_{10}$ total coliforms and *Escherichia coli* were 0.7 $\log_{10}$ and 0.7 $\log_{10}$ respectively (Table 6).

In water samples treated by biosand filters, $\log_{10}$ total coliforms reduction ranged from -0.1 $\log_{10}$ to 0.4 $\log_{10}$, which corresponded with -11.6% to 59.1% removal efficiency (Table 7). Log_{10} *Escherichia coli* reduction ranged from 0 $\log_{10}$ to 0.6 $\log_{10}$, which corresponded with 0 to 75% removal efficiency (Table 6). The overall mean $\log_{10}$ total coliforms and *Escherichia coli* were 0.2 $\log_{10}$ and 0.4 $\log_{10}$ respectively (Table 6).

In water samples treated by let it stand and settle method, $\log_{10}$ total coliforms reduction ranged from -0.5 $\log_{10}$ to 0.6 $\log_{10}$, which corresponded with -100% to 73.5% removal efficiency (Table 7 and Table 8). Log_{10} *Escherichia coli* ranged from -0.6 $\log_{10}$ to 0.0 $\log_{10}$, which corresponded with -300 to 0.0% removal efficiency (Table 6 and Table 8). The overall mean $\log_{10}$ total coliforms and *Escherichia coli* were -0.02 $\log_{10}$ and -0.35 $\log_{10}$ respectively (Table 6).

In water samples treated by aqua safe tablets, $\log_{10}$ total coliforms reduction ranged from 0.0 $\log_{10}$ to 0.2 $\log_{10}$ which corresponded with 0 to 32% removal efficiency (Table 6 and Table 8). Log_{10} *Escherichia coli* were 1.2 $\log_{10}$, which corresponded with 100% removal efficiency (Table 6 and Table 8). The overall mean $\log_{10}$ total coliforms and *Escherichia coli* were 0.08 $\log_{10}$ and 0.6 $\log_{10}$ respectively (Table 6).

Table 6: Descriptive analysis of log_{10} reductions by HWT

		Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
Log_{10} total coliform reduction	**Boiling**	0.7	0.80	0.10	0.406	0.972	-.5	2.4
	Biosand filtration	0.2	0.30	0.20	-2.598	2.939	0.0	0.4
	Let it stand and settle method	-0.02	0.40	0.20	-0.719	0.682	-0.5	0.6
	Aqua safe tablets	0.1	0.10	0.1	-0.936	1.096	0.0	0.2
	Total	0.6	0.80	0.10	0.333	.824	-.5	2.4
Log_{10} *Escherichia coli* reduction	**Boiling**	0.7	0.8	0.10	0.355	.877	-.4	2.1
	Biosand filtration	0.4	0.4	0.30	-3.524	4.126	0.0	0.6
	Let it stand and settle method	-0.3	0.2	0.1	-0.760	0.070	-0.6	0.0
	Application of Aqua Safe Tablets	0.6	0.8	0.60	-7.024	8.224	0.0	1.2
	Total	0.5	0.8	0.10	0.284	0.752	-0.6	2.1

Table 7: One-way ANOVA results showing the relationship between log_{10} reductions by HWT under household conditions

		Sum of Squares	df	Mean Square	F	Sig.
Log_{10} Total Coliform Reduction	**Between Groups**	2.720	3	0.907	1.356	0.269
	Within Groups	28.084	42	0.669		
	Total	30.803	45			
Log_{10} Escherichia Coli Reduction	**Between Groups**	3.452	3	1.151	1.981	0.132
	Within Groups	24.398	42	0.581		
	Total	27.850	45			

Table 8: Descriptive analysis of percentage reductions of total coliforms and Escherichia coli by selected HWT under household conditions

		Mean	Std. Deviation	Std. Error	Min	Max
Percentage total coliform Reduction	**Boiling**	40.2	65.3	10.6	-115.7	100.0
	Bio sand filtration	23.8	49.9	35.3	-11.6	59.1
	Let it stand and settle method	-18.1	72.4	36.2	-100.0	73.5
	Aqua safe tablets	16	22.6	16	0.0	32.0
	Total	33.3	64.9	9.6	-115.7	100.0
Percentage Escherichia coli reduction	**Boiling**	22.6	81.9	13.3	-200.0	100.0
	Bio sand filtration	37.5	53	37.5	.0	75.0
	Let it stand and settle method	-200	141.4	70.7	-300.0	.0
	Aqua safe tablets	50	70.7	50	.0	100.0
	Total	5.1	105.6	15.6	-300.0	100.0

Bacterial removal efficiency

Mean log_{10} total coliform reduction values were: 0.7(40.2%) by boiling method, 0.2 (23.8%) by biosand filtration method, -0.02(-18.1%) by let it stand and settle method and 0.1 (16%) by application of aqua safe tablets (Table 6 and Table 8). Mean log_{10} *Escherichia coli* reduction values were: 0.7(22.6%) by boiling method, 0.4(37.5%) by biosand filtration method,-0.3(-200%) by let it stand and settle method and 0.6(50%) by application of aqua safe (Table 6 and Table 8). There were no significant differences between the technologies ($p > 0.05$) as shown in (Table 7). Almost all the treatment methods showed not significant differences in removing total coliforms and *Escherichia coli* in drinking water.

Results Discussion

Sources of drinking water

Although majority respondents (95.7%) had access to the sources of drinking water, most of these sources were at high risk of contamination. Water springs which were being used by majority respondents had toilets constructed in less than 20 meters away them (Plate 1A). Shallow wells were unprotected and their mode of construction and location exposed them to high contamination. One would first step in water in order to get well positioned to collect it. Furthermore, crops were seen grown in less than 10 meters away from the water source (Plate 1B). This explains why majority of water samples from springs were associated with high total coliforms and *Escherichia coli* concentrations. Constructing toilets in close proximity to drinking water source puts it at risk of fecal contamination. In a related study by (Sivaraja, R., et al., 2014) found out that river Cauvery in India was loaded with coliform bacteria attributable to raw sewage. Additionally, (Abdulkadir, R.S., et al 2014) reported high concentration microbes in drinking water sources located in close proximity to pit latrines.

Plate 1A: Water springs and B: Unprotected shallow wells (Source: Field survey)

Household water treatment

Of all the HWT reported, boiling was noted the most common method used by both educated and uneducated people in the study area. Let it stand and settle is common in rural areas, practiced by people with low education level and the elderly. Biosand filtration method was the latest of all HWT and its uptake has considerably been low since inception.

Extensive use of boiling method in the study area is related to the fact that fuel wood is not yet a very big issue since some forests (natural and planted) still exist. The results of this study concur with research findings by (Kakulu, R.K. 2012, Rosa, G., 2010) that reported boiling method as the most popular household water treatment method with 43.6%. The present study findings however do not concur (Wright, J., et al., 2009, Sreenivasan, N., et al, 2015) who found out that water filtration, application of Water guard and let it stand and settle methods were in widespread use. In rural Bangladesh, (Ercumen, A., et al. 2015) reported that water treatment was rarely practiced among study participants with 1 – 2% of households reporting treating their drinking water. Of the 30 total households that reported water treatment, 26 were using boiling method, two were using a cloth filter and boiling, one was using chlorine tablets and one was using a commercial filter.

A reasonable percentage of respondents (24.4%) were not practicing household water treatment because; treated water had bad taste and smell, they were used to drinking untreated water and others believed that their drinking water sources were safe. The study findings concur with (Kakulu, R.K., 2012), who found out that respondents were not treating their drinking water because they believed that it is safer from the source, did not have knowledge on existing household water treatment methods and cost of household water treatment was high. These results imply that people are not well sensitized about the importance of household water treatment and the dangers related to consumption of untreated water. In a related research study by (Sodha, S.V., et al. 2011), among 28 respondents who did not treat their drinking water, 36% said consumption of untreated drinking water was their habit while 21% believed their source water was already safe.

Household water storage options

The container used to store drinking water greatly influences the quality of drinking water. A research study by (Harris, J.R., et al., 2009) found out that regardless of whether treated household water is initially of acceptable microbiological quality, it often becomes contaminated with pathogens of fecal origin during storage perhaps as a result of unhygienic storage and handling practices. Though a number of water storage options were revealed during the unannounced field study visits, majority (33.7%) respondents showed preference to 5-liter jerricans because they were generally cheap, safe to use, light and durable. Plastic buckets were preferred because were easy to clean; 20-liter jerricans were preferred because they were storing much drinking water for quite a number of days and plastic bottles were preferred because are cheap and in cases free of charge. The current study agrees with (Harris, J.R., et al. 2009) who reported that household water storage containers such as clay pots (62%), jerricans (21%), barrels (7%), buckets (5%), jugs (3%), and bottles (1%) were used by mothers before KiBS (Kisumu Breast feeding Study) clay pots were introduced.

Bacterial removal efficiency

It is significantly important to assess the effectiveness of household water treatment methods under household conditions because it indicates how well a method can improve the quality of drinking water without any external interference. The fact that most communities in Kabale District rely on unimproved water sources such as shallow wells, unprotected water springs and unprotected boreholes which are at high risk of contamination, it is important that various HWT methods should be evaluated to come out with those that can perform well under rural household conditions.

There were no significant differences in the level of microbiological effectiveness achieved across the methods. Generally all methods did not meet WHO criteria for "protective" treatment of drinking water on the basis of bacterial reduction, which requires a mean 99% reduction in bacteria (WHO, 2011) though these performance recommendations are based on laboratory based data. Bacterial reductions reported here are comparable though generally low in relation to previously reported estimates of HWT field performance (WHO, 2011). Relatively low bacterial reduction may have been achieved partly because; participants were not provided with trial HWT methods together with safe storage vessels to safeguard contamination after treatment; participants were neither advised nor taught the best practices to ensure that safe water treatment and storage is achieved. The study entirely depended

on respondents' own knowledge of water treatment and storage and none of our data collection team had engaged the community on correct use of any methods. Thus, though this study relatively assessed the performance of the methods under actual household conditions with no interventions.

Boiling method achieved mean overall total coliform and *Escherichia coli* reduction of 40.1% (0.7 $\log_{10}$) and 22.6% (0.7 $\log_{10}$) respectively, inconsistent with the study from peri-urban India where boiling reduced total coliforms by 99% (n = 1088) (WHO, 2007). The findings of the study do not concur with other studies including with those from rural Guatemala (86.2%) of Total coliforms (Rosa, G., et al, 2010), Cambodia (98.5% of *Escherichia coli* (Brown, J., et al, 2012); and Vietnam (97% of Total coliforms[Clasen,T, 2007). High bacteria concentration in boiled water under household conditions may be due to variability of boiling in practice and the risk of recontamination during storage (Brown, J., et al, 2012). High total coliforms and *Escherichia coli* concentrations in household treated water samples could have been due to prolonged storage of household drinking water and re growth of total coliforms and *Escherichia coli*. Inappropriate water storage, dipping contaminated hands and cups into stored drinking water also increase chances of high total coliforms and *Escherichia coli* concentrations in stored drinking water (Sobsey, M., et al, 2002).

Application of aqua safe tablets achieved an overall mean total coliform and *Escherichia coli* reduction of 16% (0.1 $\log_{10}$) and 50% (0.6 $\log_{10}$) respectively. Poor performance of aqua safe tablets may be attributed to the fact that users did not know how to effectively apply to aqua safe tablets. Some users believed it was just a matter of adding aqua safe tablets to water and allow it to settle for some minutes.

The biosand filtration method achieved an overall mean total coliforms and Escherichia coli reductions by 23.8% (0.2 $\log_{10}$) and 37.5% (0.3 $\log_{10}$) respectively. The findings of this study do not agree with (Stauber, C.E., et al, 2006) who found out that effectiveness of biosand filters on field tested water samples ranged from 0 $\log_{10}$ to 2.5 $\log_{10}$ (99.7%). The present study also doesn't agree with (Earwaker, P. 2006), who reported that biosand filters on average reduced *Escherichia coli* by 87.9% with 75.7% of filtrate samples with *Escherichia coli* < 10 CFU/100 ml. Poor performance of biosand filters could be due to their irregular use and poor maintenance. Most biosand filters looked not to have been in use for some time. Perhaps users re-started to use them when they heard about our research activities in their villages.

For a biosand filter to effectively remove bacteria from drinking water, it should have been regularly used for more than 22 days. This explanation agrees with (Sobsey, M.D., et al, 2008) who reported that the efficacy of biosand filters in removing microbes in drinking water varied with filter maturity, dosing conditions, flow rate, pause time between doses, grain size, and filter bed contact time. Inadequacies in biosand filter construction, operation and maintenance perhaps could further explain their poor performance in total coliforms and *Escherichia coli* removal. A study by (Clasen, T., 2006) reported that poor performance of biosand filters and low usage rates was attributed to the quality of maintenance, lack of reinforcement of educational messages and low support provided to filter users. Additionally, (Mwabi, J.K., et al, 2012) found out that poor performance of biosand filters were due to the fact that they had only been running for only two days at the time of testing, which is not adequate time for a Schmutzdecke to form.

Treatment by let it stand and settle method achieved an overall mean total coliforms and Escherichia coli reductions by -18.1% (-0.01 $\log_{10}$) and -200% (-0.4 $\log_{10}$) respectively. The present study supports UNCEF and WHO (2011) that found out that treatment methods such as straining water through a cloth or let it stand and settle were inappropriate methods for household water treatment. A study by (Mellor, J.E., et al, 2013) found out that total coliforms reduction treatment by let it stand and settle method resulted in total coliforms reduction mean 0.6 $\log_{10}$ (95% CI= -0.4 – 1.5).

Overall, 23.9% and 19.5% of paired household water samples yielded negative $\log_{10}$ total coliform and *Escherichia coli* reductions, respectively. Negative log reduction occurs when bacteria concentration in a treated water sample is higher than it was before treatment (Mwabi, J.K., et al, 2012). In the present study, negative log reduction perhaps resulted from poor handling of drinking water during storage, use of unsafe water storage options, inadequate cleaning of household water storage vessels and prolonged storage of drinking water. Negative log reductions may result from re-growth of injured bacteria which at a later time their metabolism get reconstructed and recover their growth (Mwabi, J.K., et al, 2012). Improper handling of drinking water during storage, dipping dirty hands and cups into stored drinking water and ineffective cleaning of water storage containers increase chances of storage water contamination (Mellor, J., et al. 2013). Research study by (John, V., et al, 2014) found out that earthen pots (water storage options) that had dirty rims and consumers rarely washed either their hands before taking water from them were associated with high total coliforms concentration. Additionally *Escherichia coli* can enter a dormant state but viable thus when raw water is tested, they may not be detected or detected in low numbers. After their dormancy period, they are detected in large numbers than before. This interpretations are in line with that of (Wu, F.M., et al. 2002) which state that *Escherichia coli* and *V. cholerae* can enter a dormant state, in which they are viable but not cultivable in media used for their detection.

Conclusion

The performance of HWT was generally poor. Our findings indicate that majority of treated household water samples were associated with high total coliforms and Escherichia coli. Prolonged storage of household drinking water, bacterial re-growth, inappropriate water treatment and storage, dipping contaminated hands and cups into stored drinking water perhaps increased total coliforms and Escherichia coli concentrations in stored drinking water. It is therefore important that the government should provide training local people to improve their understanding to effectively use and maintain HWT in use.

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