Research Paper

Quality of water sources in Southwestern Uganda using the compartment bag test (CBT): a cross-sectional descriptive study

Richard Onyuthi Apecu, Lucas Ampaire, Edgar Mugema Mulogo, Fred Norman Bagenda, Afsatou Traore and Natasha Potgieter

ABSTRACT

The aim of this study was to assess the bacteriological quality of water sources in the two rural areas of Uganda using the compartment bag test (CBT). In total, 200 water samples were collected from 69 different water sources and processed within 6 h of collection. Positive and negative controls were processed each day together with water samples. Physical parameters were measured *in situ*. Descriptive statistics were used to generate mean, minimum, maximum, standard deviations and percentages. The results indicated that 29% of the water sources met the National Standards and World Health Organization (WHO) Guidelines for drinking water. Sixty percent of the borehole, 44% of gravitational flow taps and 14% of roof rain water met the required standards. Of the open water sources, 75% of the rivers, 50% of open channels and 43% of unprotected dug wells plus 25% of protected springs and 9% of gravitational flow schemes had most probable number counts >100 *Escherichia coli*/100 mL of water. Most of the water sources in the study areas were not fit for human consumption without prior treatment. The CBT was found to be robust and easy to use in all field situations. The mean physical parameters of water sources were within the acceptable limits.

Key words | bacteriological assessment, CBT, *Escherichia coli*, Uganda, water quality

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INTRODUCTION

Access to safe water and sanitation is a basic human right as recognized by the United Nations General Assembly in 2010 (World Health Organization (WHO) 2010). Globally, 1.8 billion people lack access to safe drinking water (Onda *et al.* 2012; Bain *et al.* 2014a). In 2015, it was estimated that 663 million people worldwide still use unimproved water sources, including unprotected wells, springs and surface water. Nearly half of all people using unimproved drinking water sources live in sub-Saharan Africa; while one-fifth live in Southern Asia (WHO/UNICEF 2015). Three out of 10 people lack safely managed water services (UNICEF 2018). Safe drinking water and hygienic toilets protect people from disease and enable societies to be more productive economically. However, the suitability of water for various uses depends on the biological, physico-chemical and radiological properties of water. Water supply and its accessibility is Goal number 6 of the Sustainable Development Goals (SDG 6), and it aims at ensuring availability and sustainable management of water and sanitation for all by 2030 (UNDP 2015). Safe and affordable drinking

doi: 10.2166/washdev.2019.270

water for all by 2030 requires that we invest in adequate infrastructure, provide sanitation facilities and encourage hygiene. In order to achieve this target, 6.1 of SDG 6 is to have active monitoring of the microbial water quality of drinking water through the enumeration of *Escherichia coli* in water samples. Currently, the approved methods for the enumeration of *E. coli* in drinking water samples require the use of specialized equipment, including an electrically powered incubator, and entail complicated procedures that must be performed by trained personnel (Bain *et al.* 2012).

Most rural communities in Uganda lack access to improved water sources which are often nonfunctional. As of June 2018, the national safe water coverage in the rural area was estimated at 70% and 66% of the villages had valid water sources. The functionality of rural water supplies remained at 85% as of the last financial year 2017. The population using an improved water source in urban areas increased from 71% in June 2017 to 77% in June 2018 (Ministry of Water and Environment (MWE) 2018). In Uganda, the prevalence of diarrhea has remained above 20% in the past 10 years according to the UDHS data (Uganda Demographic Health Survey (UDHS) 2011). It was reported at 26% in 2006, 23% in 2011 and 20% in 2016. Children under 5 years of age are more susceptible to diarrheal disease and the prevalence is high (43%) among children aged 6–11 months (Uganda Demographic Health Survey (UDHS) 2011). In Uganda, about 33 deaths occur every day among children aged 5 years and below due to diarrheal diseases (Uganda Demographic Health Survey (UDHS) 2011). In a study conducted by Ssenyonga *et al.* (2009), he established that one in every five children under 5 years of age in Uganda had an episode of diarrhea within a period of 2 weeks. This puts diarrhea among the top diseases in children under 5 years in Uganda and is a disease of public health concern in the country (Ssenyonga *et al.* 2009). Exposure to diarrhea-causing agents is frequently related to sources of water used (Mbonye 2004; Ssenyonga *et al.* 2009; Godana & Mengistie 2013). Studies have shown that there are benefits of using water source to prevent diarrhea (Mbonye 2004).

Many areas of the world, including Uganda, that lack access to improved drinking water sources are located in remote rural regions where little or nothing is known about the microbial quality of drinking water sources used by the community and households. In such low-resource settings, which may also be very isolated, accessible methods for determining the microbial quality of drinking water sources are lacking. Furthermore, standard methods used to monitor the microbial water quality for regulatory compliance in even developed countries may be extremely difficult to use in these types of settings (Bain *et al.* 2012). Therefore, there is a need for a low-cost, portable, simple method that does not require specialized and highly skilled analysts, additional equipment and materials, such as an incubator, and can be performed onsite to determine the microbial quality of drinking water in low-resource settings (Bain *et al.* 2012; Onda *et al.* 2012).

The current standard water quality tests are expensive, complex and difficult to perform and require extraneous laboratory equipment. They require laboratory equipment and materials that may not be readily available in resource-limited settings and can be affordable for developed countries (Sobsey & Pfaender 2002). A simple low-cost water quality test, compartment bag test (CBT), has been developed in collaboration with researchers at the University of North Carolina to detect the presence of fecal *E. coli* in drinking water. The CBT is portable, equipment and specialized materials and can be performed onsite. The CBT is a polyethylene bag that was modified to provide separate internal chambers of 56, 30, 10, 3 and 1 mL sample volumes, totaling 100 mL. A Hi-E. coli test bud of *E. coli* bacteriological medium (HiMedia Laboratories, Mumbai, India) containing a chromogenic glucuronide substrate, 5- bromo-4-chloro-3-indolyl-β-D-glucuronic acid (X-gluc), is added to a water sample, and the amended water is swirled to fully dissolve the medium. Once the medium reagent is dissolved, the sample is transferred to a sterile CBT. The sample is then distributed among the five compartments by tilting the bag from side to side and manual adjustment (squeezing) of the compartment volumes. An external two-piece spring plastic clip is placed across the bag above the liquid levels in the compartments but below the tops of the compartments in order to isolate the compartments from each other. The sealed bag is then incubated at 27–44.5 °C for 18–24 h or longer at the lower temperatures of 27–30 °C, and the compartments that show bacterial growth by the presence of any trace of blue or blue–green color are considered to be positive for *E. coli* growth. The combination

of positive compartments and their volumes provides the basis for a most probable number (MPN) estimate of the *E. coli* concentration per 100 mL of water that is looked up in a probability table (World Health Organization (WHO) 2011). The CBT is portable and does not require an extensive and expensive laboratory equipment that is normally needed for current tests of drinking water quality. It is more economically feasible to test drinking water without trained personnel. The test is rapid and simple to perform. The CBT performs just as efficiently as the standard method, membrane filtration for the detection of *E. coli* in drinking water, thereby predicting the risk of waterborne disease. In developing countries such as Uganda where resources for water quality testing are limited, this valuable test can be used by the public health officers in aiding the prevention of diarrheal disease and reducing the burden of disease. The CBT has the potential of being employed in monitoring activities of the microbial water quality where there are excessive microbial levels detected in drinking water and used to support the water safety plan (Wang 2015).

Performance evaluation of the CBT for *E. coli* in drinking water has been conducted by a number of researchers. Performance of CBT was conducted to explore the use of CBT to detect *E. coli* compared to a standard test using Colilert medium in Quanti-Tray at various incubation temperatures. The CBT was also evaluated in the field settings by incorporating the CBT in a demographic household survey in Peru and Liberia. In Tanzania, a household survey was conducted to evaluate the CBT as a health behavior and education tool. The outcomes of these surveys were (i) demonstrated that the CBT detects and quantifies *E. coli* comparable to standard methods. The challenge of using the CBT in the enumeration of *E. coli* is when counts in some water samples are beyond 100 *E. coli*/100 mL water samples, it becomes Too Numerous To Count, which is not acceptable for the Uganda National Standards and WHO Guidelines for water quality. (ii) Incubation temperature between 27 °C and 44 °C provides comparable *E. coli* MPN results. (iii) The CBT can be used in low-resource settings and incorporated within national health surveys. (iv) The CBT can be used as a health behavior and education tool and can influence the perception and knowledge of the microbial water quality of household uses (Wang 2015). Stauber *et al.* (2014) evaluated the CBT and found it to be simple (no need for highly trained laboratory staff), reliable (high sensitivity and specificity), and a low-cost water quality test (a minimal need for laboratory equipment) that can be used in resource-limited settings.

In this study, an *E. coli* indicator of fecal contamination was used to assess the bacteriological quality of water sources and household storage water in the two rural sub-counties and compared the results with the Uganda Water Quality Standards and WHO Guidelines for Drinking Water. The water quality test in rural Uganda is mandated under Business and Scientific Services Directorate (DBSS) of the National Water Sewerage Corporation (NWSC) in the Ministry of Water and Environment (MWE). The department offers water quality external services through the decentralized laboratories where various water and waste water quality test can be done by trained laboratory technicians using the standard methods, which are costly and technically demanding to run. This study is the first time in Uganda a field-portable, quantitative water microbiology test to detect and enumerate the *E. coli* contamination in water samples using this valuable CBT that was successfully used.

MATERIALS AND METHODS

Research design

A cross-sectional descriptive research design was used for this study. This was chosen in order to detect and quantify *E. coli* as the indicator of fecal contamination in the household storage water and water sources being used by the study population.

Description of the study area

The study was conducted in two rural sub-counties of Bugoye in Kasese district and Rugando in Mbarara district, Uganda between July 2015 and August 2015. Kasese district is one of the districts located in the central-western part of the Western region of Uganda. Bugoye sub-county is one of the 19 sub-counties for a district that consists of two counties, one municipal council and four town councils. Bugoye sub-county located in the north of Kasese municipality is

approximately 20 km following through the Kasese–Kabarole road with coordinates 0°18′18.0″N, 30°06′00.0″E (latitude: 0.3050; longitude: 30.1000) (The Republic of Government of Uganda 2012). It has a population of about 45,220 and approximately 8,986 households. It is composed of five parishes and a total of 35 villages (The Republic of Government of Uganda 2012). Most of the sub-counties are covered by the mountainous terrain of Mount Ruwenzori which encourages the construction of gravity flow schemes that surround the mountain (Figure 1). Safe water coverage of Bugoye has increased from 31.5% in 2006 to 69% in 2008 (The Republic of Government of Uganda 2012). The main water sources in the sub-county are rivers originating from Mount Ruwenzori, water channels (used for driving the turbine), protected springs, boreholes and gravity flow scheme taps.

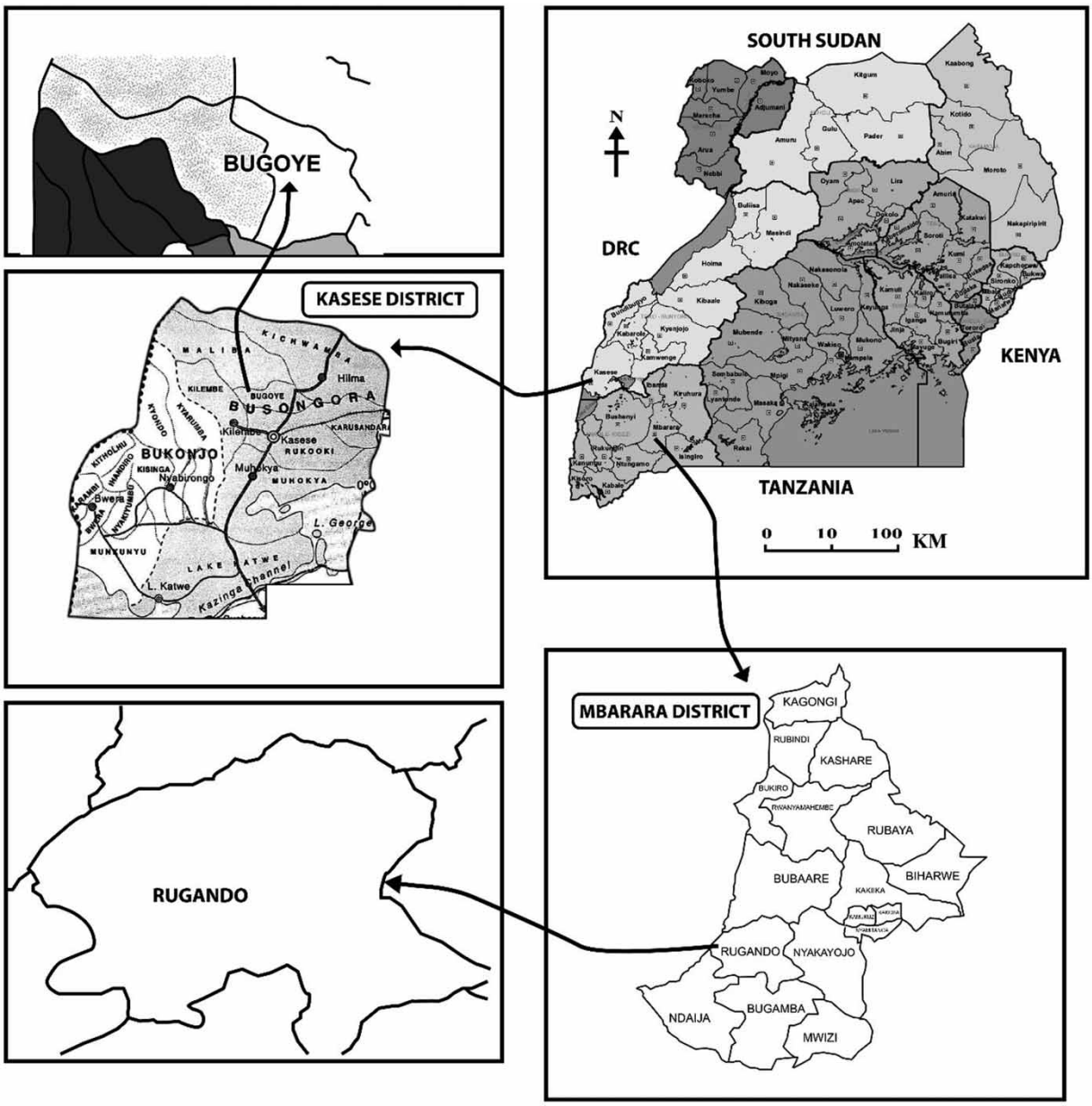

Figure 1 | Map of Uganda showing Rugando and Bugoye sub-counties.

The Mbarara district is located in the southwestern part of Uganda. It covers an area of 1,846.4 km^2. The district has a mixture of fairly rolling and sharp hills, fairly deep and shallow valleys and flat land. Rugando sub-county is found in Rwampara County, in the western part of the Mbarara district (Figure 1). It has 53 villages with five parishes. The sub-county has 6,084 households with a total population of 26,827. The terrains in the sub-county are both flat and hilly. About 70% of the terrain is flat (Nyarubungu, Mirama and Nyakabara). There are various sources of water used for both domestic consumption and drinking water in the district and in Rugando in particular 40 protected springs (2 are nonfunctional), 2 shallow wells, 3 boreholes (5 are nonfunctional), 62 rain water tanks (1 nonfunctional) and 91 gravity flow scheme taps (15 nonfunctional) (The Republic Government of Uganda 2012). The population served with safe water is at 95% (26,380). The functional water sources are at 90.4%. Latrine coverage at Rugando sub-district is at 98%. Hand washing facility for Rugando sub-county is low at 54% (The Republic Government of Uganda 2012).

Collection of water samples

Samples from the water sources were collected for 2 months from July 2015 to 1 August 2015. The month of June 2015 had doubled the long-term rainfall, but July and August 2015 were very dry (UNMA 2015). In total, 69 samples were collected from the different water sources; gravitational flow scheme (34), protected spring (4), roof rain water (7), river water (8), boreholes (5), unprotected dug well (5) and channel water (6) using the WHO water sample collection guidelines (Godana & Mengistie 2013). The water samples collected were kept at room temperature until they were analyzed. This is an advantage of handling CBT samples as it does not require the stringent measures of storing the samples at 1–4 °C as recommended by the WHO guideline for water analysis (Cotruvo 2017). The time between sample collection and analysis was restricted to within 6 h as recommended by the WHO Guideline for Water Analysis. The number of water samples collected per each parish was proportionate to the population in each parish.

Onsite measurement of physical parameters

The physical parameters (temperatures, pH, electrical conductivity, turbidity and total dissolved salts) were measured *in situ* at the time of sample collection in order to avoid the alteration/changes that are likely to occur in their values during transportation and storage. The pH/electrical conductance (EC)/total dissolved solid (TDS)/temperature meter (Hanna Instrument HI 991300) was used to measure the physical parameters. The meter was calibrated with pH 4.01 and 7.01 standard buffer solutions according to the manufacturer's instructions. Electrical conductivity calibration was achieved by using HI7031 (1,413 µS/cm) calibration solution, meter calibrated at 25 °C. The electrodes were rinsed with de-ionized water between samples. The water turbidity was measured *in situ* using a simple extinction method.

Microbiological analysis of water samples

The commercially available CBT and its methodology were followed according to the manufacturer's instructions (Aquagenx, Chapel Hill, NC, USA). Briefly, after the water sample was collected, 100 mL of each sample was poured into a sterile sample bottle and the chromogenic growth medium X-Gal (5-bromo-4-chloro-3-indolyl β-D-galactopyranoside), supplied by the manufacturer, was added to the sample bottle and swirled until all the substrate had dissolved in water (turned brown in color). The prepared water sample was then poured into the supplied CBT bag and evenly distributed into all compartments. This was achieved by manually gently squeezing the bag contents to ensure that each sample volume was filled to the set mark on the bag (HiMedia Laboratories, Mumbai, India). Each bag was sealed using a two-piece plastic clip and incubated in the incubator at 37 °C for 24 h. A positive control was an *E. coli*-positive sample while the negative control was sterile distilled water. The *E. coli* density was scored in a spreadsheet provided as MPN/100 mL of water through the combination of positive and negative compartments of the bag per sample according to the WHO (2011) water quality testing guidelines. The blue/green color was indicative of *E. coli*-positive, while the brown/yellow color indicated negative *E. coli* for the water sample. The water samples

in the CBT bag were decontaminated by adding three chlorine tablets and swirling until all the tablets dissolved and then safely discarded according to the manufacturer's specifications.

Data analysis

All information were added to an Excel spreadsheet and copied into STATA 12 for further analysis. Descriptive parameters were used to indicate mean, minimum, maximum, standard deviations and percentages.

RESULTS

Physical parameters in water sources

The mean temperature of the water sources varied from 17.7 °C (open channel) to 27.2 °C (borehole). The pH of the water sources varied from 6.1 (protected spring) to 7.6 (water channel) and TDS varied from 39.8 mg/L (open channel) to 239 mg/L (borehole). EC varied from 83 μS/cm (open channel) to 475 μS/cm (boreholes). Nearly all the turbidity of the water sources were 5 NTU or below with only one borehole source with a recorded value of 20 NTU and one unprotected hand dug well was also measured (133.2 NTU). The mean of physical parameters of the water sources fell within the acceptable limits set by the Uganda National Standards for drinking water and the WHO Guidelines (Table 1).

Microbiological quality of water sources

The percentages of the water sources with *E. coli* MPN/100 mL with WHO water quality risk categories are shown in Table 2. While 60% of borehole water met the WHO standards for safe water, only 44% gravitational flow scheme tap, 14% roof rain tank and zero percent of the protected springs met the WHO standard despite all four categories being defined as 'improved water sources' according to the WHO/UNICEF Joint Monitoring Programme (WHO/UNICEF 2015). The open (unimproved) water sources were associated with very high risk/unsafe water with MPN > 100. The rivers (75.0%), open channels

Table 1 | Physical parameters of water sources

	pH				Temperature (°C)				Electrical conductivity (μS/cm)				Turbidity (NTU)				Total dissolved salts (mg/L)			
Water source	**Mean**	**Minimum**	**Maximum**	**SD**	**Mean**	**Minimum**	**Maximum**	**SD**	**Mean**	**Minimum**	**Maximum**	**SD**	**Mean**	**Minimum**	**Maximum**	**SD**	**Mean**	**Minimum**	**Maximum**	**SD**
Gravitational flow tap ($n = 34$)	7.5	5.8	8	0.5	25.1	20.4	29.4	1.7	304	68	615	203	5	5	5	0	152.9	34	312	102.9
Protected spring ($n = 4$)	6.1	5.3	7	0.7	23.6	21.1	24.5	1.7	188	104	248	62	5	5	5	0	95.2	55	125	30
Rain water ($n = 7$)	7.2	6.3	7.8	0.6	25.6	21.0	32.1	3.3	123	29	444	145	5	5	5	0	61.4	14	223	72.7
River water ($n = 8$)	7.7	7.5	7.9	0.2	22.0	19.8	24.2	1.8	141	75	366	97	5	5	5	0	66.9	19.7	185	52.6
Borehole water ($n = 5$)	6.9	6.7	7	0.1	27.2	25.8	29.3	1.6	475	400	633	97	20	5.0	80.0	33.5	239	200	316	47.8
Unprotected dug well ($n = 5$)	6.3	5.4	7.9	0.9	26.2	23.6	27.8	1.6	313	83	452	140	133.2	5.0	501.0	214.9	156.8	42	226	70
Channel water ($n = 6$)	7.6	7.5	7.8	0.2	17.7	16.6	19.2	1.2	83	44	162	42	5	5	5	0	39.8	22	74	18.4
WHO Guidelines	6.5–8.5				Not specified				Not specified				5 NTU				600 mg/L			
Uganda National Standard	6.5–8.5				Not specified				Not specified				5 NTU				1,200 mg/L			

Table 2 | Microbiological quality of water sources using the WHO water quality risk categories

	WHO water quality risk categories			
Water source/types	**Safe <1 MPN/100 mL**	**Intermediate 1–10 MPN/100 mL**	**High risk 11–100 MPN/100 mL**	**Unsafe >100 MPN/100 mL**
Gravitational flow tap ($n = 34$; 49%)	15 (44%)	8 (24%)	8 (24%)	3 (9%)
Protected spring ($n = 4$; 6%)	–	3 (75%)	–	1 (25%)
Rain water ($n = 7$; 10%)	1 (14%)	2 (29%)	1 (14%)	3 (43%)
River water ($n = 8$; 12%)	–	1 (13%)	1 (13%)	6 (75%)
Borehole water ($n = 5$; 7%)	3 (60%)	1 (20%)	1 (20%)	–
Unprotected dug well ($n = 5$; 7%)	1	1	2	1
Channel water ($n = 6$; 9%)	–	–	3 (50%)	3 (50%)
Total = 69 (100%)	20 (29%)	16 (23%)	16 (23%)	17 (25%)

(50%), unprotected dug well (43%), protected springs (25%) and gravitational flow scheme tap (9%) had readings of MPN > 100 *E. coli*/100 mL of water sample (Table 2).

DISCUSSION

In this study, measurable concentrations of *E. coli* bacteria were found in the water samples collected from water sources using the CBT. The mean concentrations of *E. coli* MPN/100 mL of water across most water sources were above the WHO recommended level of <1.0 *E. coli*/100 mL of drinking water. A proportion of 29% of water sources were safe for drinking (<1.0 *E. coli*/100 mL of water), while the remaining 71% of the water sources were unsafe. The safe water sources were ranked as follows: borehole water (60%), followed by gravitational flow water (44%) and roof rain water (14%). Our study is in agreement with similar studies (Magrath 2006; Parker *et al.* 2010), which states that boreholes have the safest microbiological quality of water, followed by open dug wells and protected springs which were of similar quality. The ranking of the water sources was expected because as water sources are increasingly separated from the human environment, contamination pathways are reduced and hence microbiological water quality increases. Of the sources defined as improved by the WHO/UNICEF Joint Monitoring Programme (WHO/UNICEF 2015), only 29% met the WHO microbiological water quality standards, meaning virtually that a substantive proportion of the Ugandan population still lacks access to safe water. The consumption of fecal contaminated water by the community is one of the main causes of diarrheal illness in low-resource settings (UNICEF/WHO 2009). Many of these cases of illness could be avoided, if regular microbial water quality testing was performed to determine the microbial quality of drinking water, which could prompt action to remediate fecally contaminated water when found. These tests results can inform communities or households of whether their current drinking water source is safe, if they should seek other sources of drinking water, or use water treatments such as disinfection treatment before consumption.

There are many standard tests to detect and quantify *E. coli* and other fecal coliforms in drinking water; however, the tests may be complex, time-consuming and expensive (Bain *et al.* 2014b). Current methods may not be appropriate for low-resource settings. However, the CBT offers an alternative to the other tests that enable its use in these settings (Bain *et al.* 2012; McMahan *et al.* 2012; Stauber *et al.* 2014). The CBT is a novel method for quantifying *E. coli* in drinking water samples and have the potential of overcoming the barriers to microbial water quality testing in low-resource settings (Bain *et al.* 2012; McMahan *et al.* 2012). It has the potential to overcome the barrier to microbial water quality testing in low-resource settings, because it is portable, simple to perform with few steps, can be visually scored, requires no electricity, no cold chain, supporting equipment or specialized materials and can be performed onsite (Stauber *et al.* 2014; Wang 2015). The CBT performs similarly to other more complex, less portable and more expensive tests that are unsuitable for field use in low-resource settings. It can provide an opportunity to do a

widespread and routine microbiological testing of household drinking water on samples collected during the survey. The CBT therefore has a potential application for local water quality monitoring, such as water surveillance monitoring by district health officers (DHOs). Water quality monitoring is important in achieving the progressive realization of the human right to safe water (Bain *et al.* 2014b).

Another advantage of using the CBT in water quality analysis over the established standard methods is its simplicity to use and the reading/scores of CBT depend on the color changes in the media after the incubation period. The reading of the end point result using color change in the media could trigger the understanding of the concept of water contamination by the community and help to improve their health behavior and hygiene practices. Research conducted in Mwanza, Tanzania found that there exist an awareness and knowledge gap among many household members in the perception of household drinking water safety and actual microbial safety of this drinking water (Wang 2015). The CBT was found to be a potentially useful and easily implementable health behavior/health education tool. The visible color of an *E. coli*-positive chamber in the CBT, even if there is only one color positive chamber, can be powerful visible message to change the perception on the microbial safety of drinking water. The experimental results indicate that the use of the CBT can not only change perceptions on water safety and convey water safety knowledge but also increase willingness for effective water treatment actions to improve water quality. The CBT could be used in Uganda by the environmental health officers as a health behavior/health education tool to bring in change in the community.

Despite the CBT being robust in water quality analysis, it has some limitations. One of the limitations of CBT is its applicability to some types of water samples is its upper detection limit of about 100 *E. coli* MPN/100 mL of undiluted water. This concentration of *E. coli* can be achieved by many ambient environmental waters and greatly exceeds the recommended *E. coli* level of the WHO Guidelines for Drinking-water Quality which is none detectable/100 mL (World Health Organization (WHO) 2011). However, the CBT provides actionable information for decision-making about the safety of drinking water, because it quantifies and distinguishes the *E. coli* concentrations in 100 mL samples of drinking water corresponding to the WHO decimal categories of potential health risk (World Health Organization (WHO) 2011). For applications of the CBT to waters expected to have higher concentrations of *E. coli*, it is readily possible to compensate for the lower upper detection limit by first appropriately diluting the water sample in *E. coli*-free dilution water perhaps 10-fold or more, as has been reported previously for the use of the CBT to analyze a range of different ambient water samples in Atlanta, Georgia, USA (Stauber *et al.* 2014). Another limitation of the CBT is that it has only five compartments. This limited number of sample sub-volumes results in somewhat broader confidence interval estimates of the MPN concentration of bacteria than those of other MPN tests that employ a greater number of discrete sample volumes. However, the upper 95% confidence limit values of MPN of the CBT are not so large in magnitude relative to the MPN concentration estimates that the water would be classified differently on the basis of the WHO decimal categories of *E. coli* concentration/100 mL.

The mean of physical parameters of the water sources fell within the acceptable limits of the Uganda National Standard for drinking water and WHO Guidelines (World Health Organization (WHO) 2011; UNBS 2014). There were remarkable differences in temperature values between the different water sources in the study areas with the lowest temperature mean recorded from open water sources (channel water and rivers) with temperature and the highest mean temperature was from the boreholes. The high temperature of water in boreholes may be due to a consequence of not having purged the rising main before sampling or since the boreholes are located near Ruwenzori Mountains, it could be related to geothermal activities of the mountains. The high temperature in drinking water affects the esthetic properties but generally warm water is undesirable for drinking (Oyem *et al.* 2014).

The pH of the water sources was within the acceptable limits of WHO for drinking water. Although pH values have no direct impact on consumers, its control can ensure the satisfaction of water clarification and disinfection (pH less than 8.0). The value of pH less than 7.0 is likely to cause corrosion which can result in the contamination of drinking water and in adverse effects, on its taste and appearance which will undermine the confidence of consumers and could lead to the use of water that are microbiologically less

safe (World Health Organization (WHO) 2011). Nearly all the turbidity of the water sources were below 5 NTU with the exception of one borehole source and one unprotected hand dug well water source. Turbidity in water is caused by suspended particles or colloidal matter. It may be caused by inorganic–organic matter or a combination of the two. Microorganisms are particularly attached to particulates that can be a threat to health. Turbidity can seriously interfere with the efficacy of disinfection by providing protection for organisms (World Health Organization (WHO) 2011). Turbidity can also have a negative impact on consumer acceptability of water as a result of cloudiness. Turbidity of water can be used as a proxy for the presence of contaminants that would be of concerns for health, especially inadequate treated or unfiltered water (Aramini 2004; Tinker *et al.* 2010; Beaudeau *et al.* 2014; Hsieh *et al.* 2015).

CONCLUSIONS AND RECOMMENDATION

This study has shown that the water in the study area was not fit for human consumption without prior treatment. The high number of *E. coli* counts observed in the two sub-counties reflected the poor quality of water used by these community members. There is an urgent need for the protection of water sources in the rural communities supported by a strong environmental awareness campaign to help rural communities to participate positively to protect and manage the quality of their water sources. To overcome the drawbacks of the existing microbial water testing methods (which are expensive, time-consuming and require expertise and fully equipped laboratories), the CBT kit proved to overcome these challenges. The CBT should be used as a health behavior/health education tool to improve the perception of water quality issues by the community. We therefore recommend the roll out of CBT by all public health officers at the districts/communities at village levels to monitor the microbiological quality of water sources.

LIMITATIONS

This study was conducted in two rural sub-counties of Rugando Mbarara district and Bugoye in Kasese district – in Southwestern Uganda. However, the two sub-counties reflect a typical picture of such settings in Uganda where most communities rely on the use of water from open sources for both drinking and domestic use. The water sample collection period was too short and besides the water sample was collected during the dry season, so the seasonal variation in the water quality parameter during the wet season was not assessed.

DECLARATION

Ethics approval and consent to participate

The research proposal was reviewed and approved by the Research Ethics Committee (REC) [REC. No. 06/2015] of the Mbarara University of Science and Technology. Permission to collect water samples was obtained from the respective Chief Administrative Officers (CAOs) and District Health officers (DHOs) and District Water Officers (DWO) of Kasese and Mbarara districts.

Consent for publication

Not applicable.

Availability of data and material

All data supporting our findings are contained in the paper. There are no restrictions to data sources; however, details of the full data may be accessed through Professor Richard Onyuthi Apecu.

COMPETING INTERESTS

The authors declare that there are no competing interests.

FUNDING

The research was financially supported by a grant from WELLCOME TRUST, UK to the Scientist Networked for Outcomes from Water and Sanitation (SNOWS) consortium

(http://www.african snows.org/). The WELLCOME TRUST, UK did not participate in the design, data collection, analysis and interpretation of data or the writing of the paper.

AUTHORS' CONTRIBUTIONS

ROA participated in the conception, design, data collection, analysis, drafting and approval of the manuscript. LA participated in the conception, data collection and approval of the manuscript. EM participated in the conception, drafting and approval of the manuscript. FB participated in the conception, design, drafting and approval of the manuscript. AT participated in the conception, design and approval of the manuscript. NP was PI of the project and participated in the conception, design, drafting, training and final approval of the manuscript.

ACKNOWLEDGEMENTS

The study team is grateful to the WELLCOME TRUST and SNOWS consortium, the Directorate of Research and Innovation University of Venda for providing the funds for the different aspects of this study. We further extend our sincere gratitude to the management of the Mbarara University of Science and Technology (MUST) for the support they rendered to a member from MUST to attend the workshops in the University of Venda to finish final write up of the manuscripts. To the data collection team: Mr Santos Omac, Michael Matte and Andrew Wesuta for the wonderful work done during sample collection and analysis using the CBT.

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First received 23 October 2018; accepted in revised form 16 September 2019. Available online 9 October 2019