Practical Paper

Microbiological analysis of domestic water sources in Banda slum of Kampala, Uganda

Barugahara Evyline Isingoma and Kwesiga Stephen

ABSTRACT

There is scarcity of information about the safety of water in Banda slum of Kampala, Uganda and yet reports indicate outbreaks of infectious diseases such as typhoid fever and cholera. The aim of this study was to determine the risk of exposure to waterborne infections by Banda residents due to faecal contamination of water sources. Four hundred respondents were sampled and interviewed on the methods of water collection, treatment and storage. Water samples were collected with sterile glass bottles in duplicate from the dug well, protected spring and piped water system in December 2018 on two different consecutive days. They were transported to the laboratory for total and faecal coliform count analysis within 2 h using a lightproof-insulated box containing ice-packs. The mean *Escherichia coli* count for the dug well was 43 ± 18 c.f.u/mL. The protected spring had no detectable *E. coli*, but its total plate count level was 76 ± 1.4 c.f.u/mL. Only 46% of the respondents treated their drinking water using boiling and filtering methods. Poor sanitation and hygiene practices were observed. The total and faecal coliform counts of water sources were unsatisfactory making Banda residents highly at risk of infectious diseases, given the small number of residents that treated water.

Key words | Banda slum, domestic water, microbiological, Uganda

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HIGHLIGHTS

- There are reports of waterborne diseases in Banda zone.
- Lack of data on water sources and treatment methods in Banda slum.
- Poor sanitary conditions in this slum.
- Highly populated area with few social amenities.
- Low educational levels of inhabitants.

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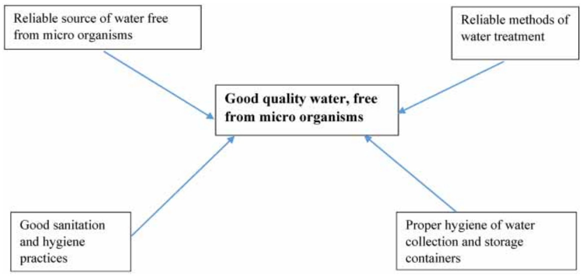
GRAPHICAL ABSTRACT



INTRODUCTION

Water is a very important natural resource since without it life cannot exist. There is no substitute for water in many of its uses and yet it has considerable potential for contamination (Rosa & Clasen 2010; Kabwama *et al.* 2017). This creates the need to ensure the availability of good quality water. It is estimated that one-third of deaths in developing countries are caused by the consumption of contaminated water (Kimani-Murage & Ngindu 2007). Though access to safe drinking water is considered a human right, this is still a challenge in many developing countries like Uganda (WHO 2015; Ssemugabo *et al.* 2019). Worldwide, slums pose an important threat as far as supply of safe water is concerned. This is because they are characterised by overcrowding, inappropriate technology and poor sanitation facilities resulting in WASH-related infections such as typhoid fever, dysentery, and cholera among others (Musoke *et al.* 2018). Diarrhoea is among the major contributors of under-five mortality among children, and 88% of all diarrhoea diseases are due to poor sanitation, hygiene and unsafe drinking water (Ibrahim *et al.* 2016). Kampala is Uganda's capital city and 53.6% of its population live in slum settings (Ssemugabo *et al.* 2019) where there is a high rate of informal settlement growth, estimated at 9.6% per annum in some slums (Kulabako *et al.* 2010). In many of these informal settlements, access to safe drinking water is still a challenge resulting in increased malnutrition and waterborne diseases such as diarrhoea, especially among children under 5 years (Tumwebaze & Lüthi 2013; WHO 2015). The poor state of sanitation in Kampala slum areas is reported to contribute to the contamination of 85% of the protected spring water sources (Tumwebaze & Lüthi 2013).

Banda slum is found in the Nakawa division of Kampala city. It is reported to have the highest number of households in the division with a total population of 50,000. Information about safety of different sources of water for domestic consumption and household hygiene management practices in Banda slum is scanty. Interventions in water, sanitation and hygiene have been done by Community Integrated Development Initiatives, Act Together and National Water and Sewerage Corporation through improving access to water and sensitising the community about the importance of hygiene and sanitation. The area network, however, is still lacking in terms of proper sanitation and hygiene (Zziwa 2019).

In order to ensure safe water, it is important that the whole chain from collection, transportation, storage and treatment processes are all acceptable (Ssemugabo *et al.* 2019).

This study therefore seeks to determine the risk of exposure to infectious diseases related to faecal contamination of water by Banda residents through analysing the major sources of water, the sanitation and hygiene practices, especially the methods of water collection, treatment and storage.

METHODOLOGY

Study site and population

This research was conducted in Banda slum, a region located in the outskirts of Kampala, Uganda's capital city. Banda is found east of Kampala city centre about 5 km away, along the Kampala-Jinja road, latitude 0° 21′ 10. 79″N, longitude 32° 37′ 31. 79″ E with an elevation of 1,240 m. It covers a total area of approximately 150 acres of land, and there are around 2,800 structures in Banda. Figure 1 is a map showing the location of Banda.

Information gathered from local council leaders based on service provision exercises indicates the population of Banda to be 50,000 with an average household size of five people. It accommodates different ethnic groups most of whom have migrated from rural areas to the city in search of employment. Most of the residents are illiterate and semi-illiterate and are mostly engaged in market vending.

Study design

The study was a descriptive cross-sectional survey carried out in homesteads of Banda slum. There was also microbiological assessment of water quality carried out in the Food Science and Technology laboratory of Makerere University.

Sampling procedures and sample size determination

Kampala city was sampled because of the high growth rate of informal settlements and the reported incidences of WASH-related infections (Kulabako *et al.* 2010; UBOS 2014; Ssemugabo *et al.* 2019). Banda slum was sampled because it is reported to have the highest number of households in Nakawa division of Kampala city. There is also scarcity of information about water, sanitation and hygiene practices of Banda residents and yet just like other slums worldwide, and its residents are highly vulnerable to waterborne disease infections due to the poor living conditions in slum areas.

Basing on Morgan's Table by Krejcie & Morgan (1970), 400 households were sampled. Households were chosen by systematic random sampling where the head of the 10th household was interviewed.

Data collection tools

Close-ended, semi-structured and self-administered questionnaires were used to collect data on hygiene and sanitation practices, sources of water, methods of water collection, treatment and storage, and knowledge and attitude toward water treatment. Prior to the data collection exercise, questionnaires were pretested in Mulago slum within Kampala city. This slum has almost similar conditions as the study area locality. The tool was then standardised and validated with some adjustments. Trained research assistants who were Home Economics student teachers of Kyambogo University collected the data.

Sampling and sample preparation for microbial analyses

Two public taps, the protected spring and dug well, were sampled because they are the major sources of water in the area. Prior to the collection of water samples, bottles of 500 mL capacity were thoroughly cleansed and rinsed carefully before they were sterilised at 121 °C for 30 min (using American electric pressure steam sterilisers model 25×). The water samples were collected in December 2018 within 2 days during the dry season though some occassional rains were experienced.

Samples of water were taken in duplicate from each of the selected water sources by holding the bottle near its base in the hand and allowing the water sample to enter the bottle by its mouth. The sampling bottle was not filled up to the brim and 20–30 mm space was left for effective shaking of the bottle (APHA 1998). All samples were transported to the laboratory using a lightproof-insulated box containing ice-packs to ensure rapid cooling. Microbiological analysis of water samples was started within 2 h after collection to avoid unpredictable changes in the microbial population (Gaudy 1998). The samples were analysed for total and faecal *coliforms* counts, the major indicators of microbial contamination from Makerere University, Department of Food Science and Technology laboratory.

Laboratory analysis

The pH of water samples was taken immediately after water collection at the respective water sources using a digital calibrated pH meter (744 Metrohm, Germany). The pH meter was calibrated using standard calibration solutions using two pH buffers (4.01 and 7.01). The procedure for obtaining pH was repeated at the laboratory to observe if variations occurred after transporting the samples.

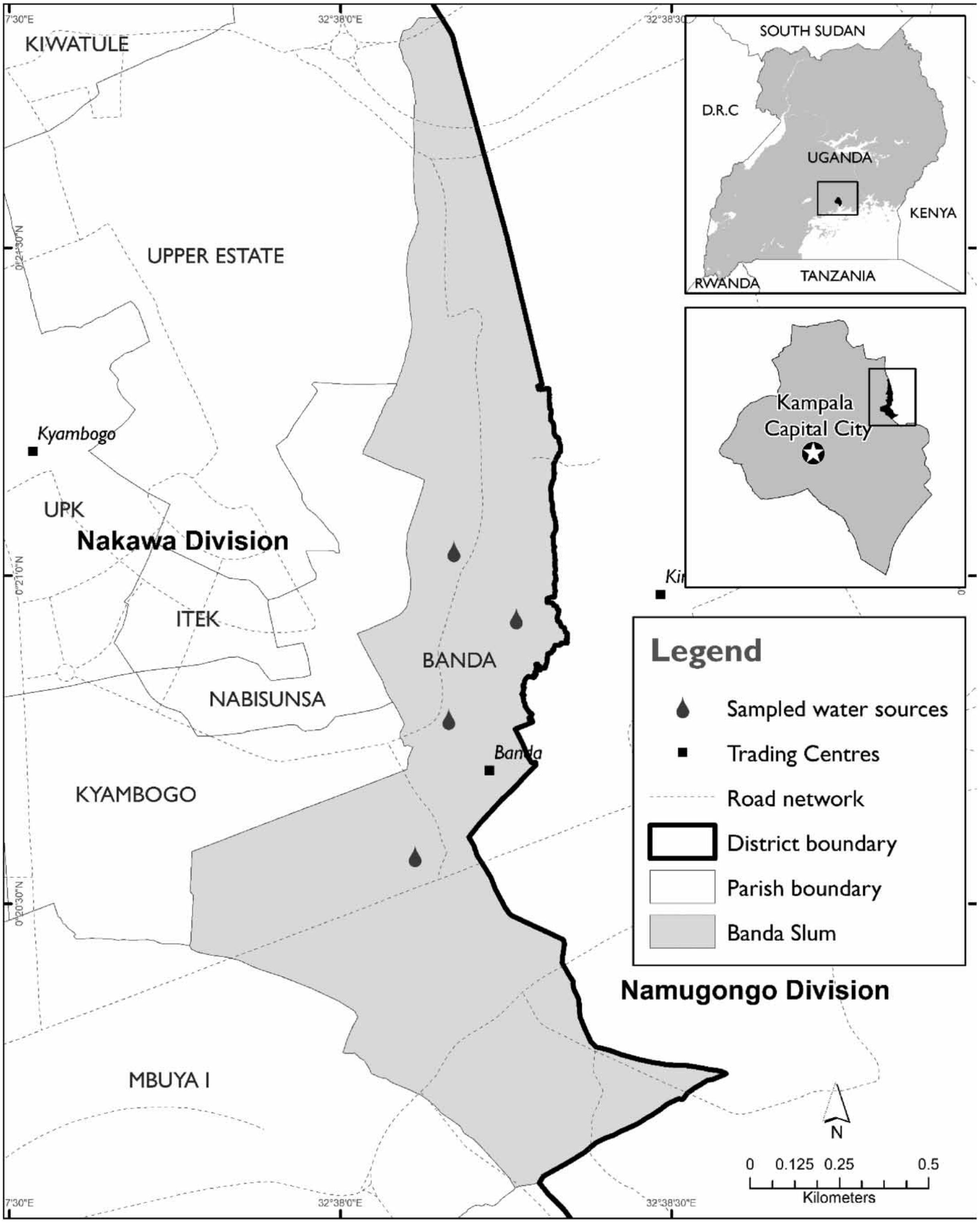


Figure 1 | Location of water sample collection points within Banda slum.

Rationale for the determination of total plate count in the study

The total plate count test was conducted to establish coliform organisms which are a suitable microbial indicator of drinking water quality, largely because they are easy to detect and enumerate in water. The coliform test is used as an indicator of the integrity of the water source and distribution system. The coliform test is also useful for monitoring the microbial quality of treated piped water supplies (WHO 1996).

Total plate count

A standard total coliform count was performed by the membrane filtration technique (WHO 1996; APHA 1998). One millilitre of water was homogenised with 9 mL of sterile peptone water solution (oxoid) and further diluted as appropriate. One millilitre sub-samples of appropriate dilutions were spread in duplicate on the pre-dried surfaces of plate count agar (Merck 5463, Germany) incubated at 37 °C for 24 h. After incubation, duplicate plates having less than 300 colonies were used to estimate the number of microorganisms in the sample. Counting was done using a colony counter (Quebel Colony Counter). The colony count millilitres of water was computed as the number of colony forming units per millilitre of diluents × dilution factor = number of bacteria c.f.u/millilitre of sample.

Enumeration of *coliforms* in water

Enumeration of coliforms in water samples was conducted using the multiple-tube method, which is also referred to as the most probable number (MPN) method. This method is based on an indirect assessment of microbial density in the water sample by reference to statistical tables to determine the MPN of microorganisms present in the original sample (WHO 1996). One millilitre of water was homogenised with 9 mL of sterile peptone water solution (oxoid) and further diluted as appropriate. Water samples (1 mL) of the decimal dilutions were pipetted into each of the three separate tubes of MacConkey broth (Oxoid 5a) with inverted Durham tubes followed by incubation at 37 °C. After 24 h, the tubes that were positive for *coliforms* were recorded, and referring to MPN tables, the MPN value was noted.

Enumeration of *Escherichia coli*

One litre of water was added to 9 mL of sterile peptone water solution (oxoid) and further diluted as appropriate. This was mixed properly and five successive dilutions were considered for each sample. One millilitre of each of the dilution was pipetted aseptically to three tubes of sterile MacConkey broth (oxoid CM5a) fitted with a Durham tube followed by incubation at 44.5 °C for 24 h. Positive tubes and their respective dilutions were recorded at the end of incubation, and counts were determined using MPN tables (WHO 1996).

Statistical analysis

Data were entered using Statistical Package for the Social Sciences (SPSS) version 20. Descriptive statistics were used to assess and summarise data. Respondents who answered 80% of the knowledge and attitude questions well were regarded to have good knowledge and attitude and *vice versa*.

All data for pH and microbial analysis were grouped according to the different sources. Mean standard deviation and coefficients of deviation were compiled. Chi-square was used to test associations between the level of education of the head of household and the practice of treating water. The level of association was set at $p < 0.05$.

Ethical considerations

The study was supported by Kyambogo University, Department of Human Nutrition and Home Economics. The Department has a working relationship with Banda community attained through the university's mission to support community development through research and innovation. A letter of introduction to Banda Local Council Chairman was obtained, and househeads who consented to the study signed a form.

RESULTS

Socio-demographic characteristics of respondents

A total of 400 households participated in the study. The majority of househeads (60%) were aged 25–34 years and 64% were females. Half of the household heads had no formal education, and the household size of the majority of respondents was comprised of 5–6 members. Water collection was done by women in the majority of households (80%; Table 1).

Quality of water drawn from water sources in the area

The mean total plate count of water samples collected from the various sources ranged from 76 ± 1.4 to 2,300 ± 210 c.f.u/mL and did not show any marked variation between all the different water sources (CV = 51.5%). The total plate count of the water drawn from the dug well was the highest with the mean of 2,300 ±210 c.f.u/mL, while the total plate count of the water drawn from the protected spring source was the least with the mean of 76 ± 1.4 c.f.u/mL.

The pH of water samples collected from the various sources ranged between 5.12 and 6.52 and did not show any marked variation within the same source (CV <4%). The pH for the dug well and the protected spring were less than 6.5 (Table 2).

The mean *coliform* of water samples ranged from (0.6 ± 0.1) to (6,500 ± 3,200) c.f.u/mL and showed a marked variation between all the different water sources (CV = 87.5%). Water samples drawn from the dug well had the highest level of *coliforms* with the mean of (6,500 ± 3,200 c.f.u/mL) and *Escherichia coli* with the mean of (43 ± 18 c.f.u/mL). Water samples collected from the kiosk tap, however, had the least number of coliforms (0.6 ± 0.1 c.f.u/mL), and samples from the protected spring had no detected *E. coli*. The mean *E. coli* counts of the sampled water sources ranged from 0 to 43 ± 18 c.f.u/mL and showed a marked variation between all the different water sources (CV = 59%; Table 3).

Table 1 | Socio-demographic characteristics of respondents

Characteristic	Frequency (*n*)	Percentage (%)
Age of household-head (years)		
Below 18	40	10
25–34	240	60
35–44	80	20
45 and above	40	10
Sex of household-head		
Female	256	64
Male	144	36
Education level of household-head		
No formal education	200	50
Attended some primary education	120	30
Completed primary education	80	20
Size of household		
Fewer than 3 members	120	30
4–6 members	240	60
7 and above members	40	10
Persons fetching water		
Children	60	15
Women	320	80
Men	20	05

Sources of water and treatment methods used

The dug well and spring were the most utilised sources of water by the majority of respondents, 86 and 79%, respectively, while most of the respondents (54%) never treated their water before drinking. All the respondents had good knowledge of the dangers of drinking contaminated water, but the attitude exhibited towards boiling water among 30% of the respondents was negative (Table 4). There was

Table 2 | Total plate count (c.f.u/mL) and pH of water samples collected from four sources of water in Banda slum[a]

	Total plate count			pH of water		
Water source	Mean	SD	%CV	Mean	SD	%CV
Protected spring	76	1.4	1.8	5.12	0.01	0.2
Dug well	2,300	210	9.1	5.70	0.20	3.5
Local council tap	160	11	6.9	6.48	0.4	0.6
Kiosk tap	120	4.5	3.8	6.52	0.04	0.6
All	660	340	51.5	5.96	0.60	10.0

[a]Values shown are means, standard deviations (SD) and coefficients of deviation (CV) of two determinations.

Table 3 | Microbial counts (c.f.u/mL) of water samples collected from four sources of water in Banda slum[a]

	Coliforms			*E. coli*		
Water source	**Mean**	**SD**	**%CV**	**Mean**	**SD**	**%CV**
Protected spring	0.7	0.2	28.6	0	0	0
Dug well	6,500	3,200	49.2	4.3	18	41.9
Local council tap	6.3	2.3	36.5	0.2	0.1	50
Kiosk tap	0.6	0.1	16.7	0.2	0.1	50
All	1,600	1,400	87.5	11	6.5	59

[a]Values shown are means, standard deviations (SD) and coefficients of deviation (CV) of two determinations.

Table 4 | Sources of water, methods of treatment used and attitude towards water treatment

Source of water	***n***	**%**
Tap	278	75
Spring	292	79
Dug well	318	86
Method of treatment		
Boil	126	34
Filter	63	17
None	200	54
Attitude towards water treatment		
Positive	280	70
Negative	120	30

no association between the practice of treating water and the level of education of household-head ($p > 0.05$).

Water collection and storage containers and frequency of cleaning them

Twenty litre jerrycans were the most used containers in the collection of water, while buckets were commonly used for storage purposes. Half of the study population cleaned water containers daily (Table 5).

Observations made around the place showed that the dug well and the local council tap were not protected while the kiosk tap and the spring were protected. The distance from the pit latrine to both the dug well and the spring was greater than the recommended 30 m. At the time of the visit, the environment around all water sources was muddy, especially the unprotected sources of water. The smell around the water premises indicated presence of faeces in the nearby vicinity. Almost all jerrycans observed were dirty with algae growth (Table 6).

Table 5 | Water collection and storage containers and frequency of cleaning them

Variable	**Frequency (*n*)**	**Percentage (%)**
Water collection containers		
Jerrycans	352	95
Buckets	18	05
Water storage containers		
Buckets	200	50
Jerrycans	88	28
Claypots	112	22
Frequency of cleaning		
Daily	185	50
Once a week	93	25
Twice a week	74	20
Rarely	18	05

DISCUSSION

Socio-demographic characteristics of respondents

The majority of family heads were females with no formal education. The people involved in the collection of water were also mostly women. According to Ssemugabo *et al.* (2019), female household heads are likely to ensure a safe water

Table 6 | Observation checklist

Parameter	**LC tap**	**Kiosk tap**	**Spring**	**Dug well**
Protected	No	Yes	Yes	No
Distance to latrines	<15 m	<15 m	>30 m	>30 m
Hygiene nearby the source	Very muddy	Fairly muddy	Fairly muddy	Muddy
Noticeable smell	Faecal	Faecal	Faecal	Faecal
Hygiene of water jerry cans	Much algae	Much algae	Much algae	Much algae

LC tap, local council tap.

chain management system than male-headed households. There was no househead with post primary education and yet education has been associated with improved safe water chain management practices (Fotue 2013).

Microbial quality of the water

Almost all the water sources had very high *coliform*s and *E. coli* counts, especially the dug well. World Health Organization suggests a zero *E. coli* count and *coliforms* counts per 100 mL of water sample (WHO 2011). Results for this study can also be compared with a study in Kenya where the mean *coliform* level of 27,500 and 9 c.f.u/mL for *E. coli* were analysed for the dug well and spring water sources, respectively (Onyango et al. 2005). These results are in agreement with reports by Haruna *et al.* (2005) where water sources in slum areas of Katwe and Kisenyi parishes were found to be contaminated with faecal bacteria. Access to safe drinking water in the informal settlements of Kampala has been reported to be a challenge by many researchers, and Banda slum seems to be following the same trend (Tumwebaze & Lüthi 2013; WHO 2015; Ssemugabo *et al.* 2019). Reports by Ssemugabo *et al.* (2019) indicates spring sources of water in Kampala to be highly contaminated because of poor sanitation facilities which was a challenge even in Banda slum. Though the protected spring in Banda had a zero *E. coli* count, this cannot eliminate the possibility of infection given the presence of coliforms in water.

Many households preferred to drink piped water supplied by the National Water and Sewerage Corporation which they regarded to be safe, contrary to results obtained. This calls for the need to educate the members of this community about the importance of treating water obtained from all the different sources, since they are all liable to contamination. Organisations such as Act Together and Community Integrated Initiatives have been educating this community about the importance of good hygiene and sanitation. However, the magnitude of this problem is big since the population is ever increasing and changing as well, calling for continuous education and support from other stakeholders. World Health Organization guidelines for untreated sources are expressed in terms of water quality at the point of collection, and this leaves no obligation to ensure quality at the point of consumption (Rosa & Clasen 2010). The high counts of *E. coli* and *coliforms* in the samples collected can be attributed to the rampant leakages in the plumbing systems of transmission and distribution of water, and there is also a high risk of water coming in contact with sewage or other contaminating agent in this slum (WHO 2015). According to World Health Organization (2011) guidelines, the presence of coliforms in treated water supplies suggests inadequate treatment, post treatment contamination, or excessive nutrients.

The pH of water samples collected was below a pH value of 7, the normal for pure water and was regarded as acidic. The pH of the dug well and the protected spring were less than the normal range for surface water (6.5–8.5) and the normal range for ground water system (6–8.5) (APHA 1998).

Sources of water

The dug well and the protected spring were the most commonly utilised water sources. This is contrary to other research findings by Ssemugabo *et al.* (2019), Kulabako *et al.* (2010) and Tumwebaze & Lüthi (2013) where piped water supply by the NWSC was reported as the most utilised source of water by over 80% of the households and yet water from the dug well and the protected spring were available at no cost in all these reports. Though the National Water and Sewerage Corporation has tried to improve access to water in this area, there is still a big challenge of catering for this ever increasing population in the slum as evidenced with long queues of people collecting piped water from these two sources. The variations in results could be an important pointer to differences among slums in terms of access to water sources. Twenty percent of the household heads that used water from the protected spring claimed that it tasted well and 30% of the respondents used the water from the dug well for other household chores and not drinking since they regarded it unsafe. In order to prevent infections, it is very important that even water used for household chores such as washing cups and preparation of salads is treated since it could easily result in infections (Ssemugabo *et al.* 2019).

The piped sources of water were in close proximity to the pit latrines (15 m) which could contribute to the contamination of water by microorganisms (Saturday *et al.*

2016). The distance of the dug well and protected spring from the pit latrine was estimated to be greater than 30 m, which does not pose a health threat (Kimani-Murage & Ngindu 2007). The possible source of contamination for the dug well must have been unhealthy practices like defaecating near the water sources and presence of pollution sources such as solid waste and absence of diversion ditches (Haruna *et al.* 2005).

Household water treatment

Only 34% of the study population boiled water. This can be compared with 32% of the study population in a Kenyan slum (Kimani-Murage & Ngindu 2007) and 89% of the households who boiled water in a Ugandan study (Bukenya 2008). Boiling is known to be the most popular water treatment method, especially for low-income countries (Rosa & Clasen 2010). However, for boiling to be effective, there is need for prolonged heating to destroy protozoa cysts and ova which was contrary to what was done by more than 50% of those who boiled water in this study (Kimani-Murage & Ngindu 2007). According to Saturday *et al.* (2016), effective boiling reduced mean *coliform* and *E. coli* levels to 40.1 and 22.6%, respectively, in a study in Kabale, Western Uganda. Half of the study population never treated water. This is in line with other scholars in Uganda and could partly be responsible for the high occurrence of waterborne diseases in Kampala district (Kabwama *et al.* 2017; Ssemugabo *et al.* 2019). Boiling is known to be a reliable method of water treatment, especially if water is stored well after (Ssemugabo *et al.* 2019). A small percentage of the population used a piece of cotton cloth for filtering water, especially those who got water from the dug well. Reports indicate that simple filtering methods like use of a folded piece of cotton cloth reduced diseases in cholera plagued countries by a half (Colwell 2003). However, for this method to be very effective, it is advised that the water is boiled afterwards (Rosa & Clasen 2010). There is need to ensure clean water from the source to collection, storage and use if we were to avoid infections (Ssemugabo *et al.* 2019). A study in Kabale District of Uganda showed the concentration of total *coliforms* and *E. coli* in untreated household test water samples to range from 0 to 496 and 0 to 242 c.f.u/100 mL, respectively (Saturday *et al.* 2016). This supports the need to ensure safe chain water management system at all stages. There was no association between water treatment and the level of education in this study, perhaps because the majority of househeads were of low education level. Though all the respondents reported good knowledge of the dangers of drinking contaminated water, the attitude of 30% of the study population was negative towards boiling water and this has been reported by other scholars (Ibrahim *et al.* 2016). They did not see the reasons why they should sacrifice money which could be used for food to boil water. This means that a great deal is still needed in terms of attitude change, especially given the limited financial resources among the slum population.

Cleaning of water sources, water collection and storage containers

Drawing water with dirty containers, washing around the water premises has been noted to cause infection in Kenyan slums calling for educative measures to prevent it (Kimani-Murage & Ngindu 2007). Hygienic practices in this area were lacking as evidenced with muddy surroundings perhaps because of the high population depending on the taps for their water. Practices such as defaecating everywhere and use of dirty containers break the safe water management chain and should be discouraged (Ssemugabo *et al.* 2019). Twenty litre jerrycans were used by 95% of respondents to collect and store water compared with 5% that used buckets. Jerrycans are small-mouthed containers and therefore can better control contamination compared with buckets. However, though reports indicated that they were cleaned daily, many of them had algae growth indicating poor cleaning methods which could lead to water contamination. There was need for thorough scrubbing to remove the green growth. Improved collection and storage containers have been associated with 69% reduction in geometric mean FC count (Rosa & Clasen 2010).

It is known that significant contamination can occur when water is drawn with dirty containers, cups and hands. This must have greatly impacted the dug well where people could immerse dirty containers in the water. On the contrary, the protection provided to the spring helped to safeguard water from such contaminants (Ssemugabo *et al.* 2019).

CONCLUSIONS

The microbiological level of water sources in Banda are unacceptably high. This is mainly due to contamination by *coliforms* and *E. coli* due to poor sanitation in Banda slum. Unhygienic collection and storage of water and failure to provide proper water treatment further aggravate the situation. There is need to improve the level of awareness about the dangers of consuming contaminated water, and the combined effort needed to ensure water is safe right from the point of collection to the point of consumption.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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