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ASSESSMENT OF THE QUALITY OF ROOF HARVESTED RAINWATER: A CASE STUDY OF KYENGERA TOWN COUNCIL, AKISO DISTRICT.A CROSS-SECTIONAL STUDY.

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ABSTRACT

Introduction

To assess the knowledge about the quality of roof-harvested rainwater for domestic use and determine the prevalence of coliforms and *E. coli* in roof-harvested rainwater in Kyengera Town Council, Wakiso district.

Methods

Across cross-sectional survey was conducted in Kyengera town council on the homesteads that performed roof rainwater harvesting between December 2022 and January 2023 on a sample of 196 homesteads.. Quantitative data was analyzed by using SPSS version 26.0 and presented in a tabular form using frequencies and percentages for easy interpretation. Bar graphs, box and whisker plots, and pi-charts were used to represent the data.

Results

The participants were mainly male (52.9%), aged 46-60 years (55.1%), with education level above secondary (55.1%) and non-formal employment. The majority of them (55.1%) had harvested rainwater for over 10 years.

Most of the samples were collected from inhabitants of Kitemu and Kyengera with 17.3% each. The results have shown that 94 (48.0%) of the samples were suspected to contain total coliforms with colon-forming units ranging from 2 to 250x105/ml. The prevalence of *E. coli* was 7.14%. Finally, 96.9% of the participants were aware of the influence of RHRW quality on its use as well as the potential contaminants of RHRW but needed to be reminded about tank cleaning.

Conclusion

The contamination of the roof-harvested rainwater collected within Kyengera town council with *E. coli* and other coliforms was high and is exacerbated by poor water tank hygiene.

Recommendation

Treatment of roof-harvested rainwater should be done before consumption of the water due to the associated contamination with coliforms and *E. coli*. This will reduce the prevalence of total coliforms and E. coli in roof-harvested rainwater which would cause waterborne diarrheas.

Keywords: Assessment, Quality, Roof, Harvested, Rain Water
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Background to the study

Access to safe drinking water is a fundamental human right (WHO, 2011). However, one-sixth of the world's population lacks access to safe drinking water (UNICEF, 2019). Of these, half are from sub-Saharan Africa (Murphy *et al.*, 2017). Besides, 368,000 people in sub-Saharan Africa (SSA) die annually from water sanitation and hygiene (WASH) related diarrhea (Prüss-Ustün *et al.*, 2014). This has been implicated in the microbial contamination of the water sources (Malema *et al.*, 2018). Of these microbes, the World Health Organization has singled out *Escherichia coli* and estimates 1.8 billion drinking water sources in SSA to be contaminated with *E. coli* which is a marker of fecal contamination. This poses a potential risk of exposure to waterborne diseases (Chouhan, 2015). Moreover, the intake of contaminated water is implicated in causing the deaths of about 1.6 million children globally under the age of 5 years (Bain *et al.*, 2014).

In Uganda, major sources of drinking water are borehole water, open well water, spring water, tap water, and roof-harvested rainwater (Musoke *et al.*, 2018). With the increasing urban population in small towns elsewhere in Africa (Tacoli, 2017) and in Uganda (IOM, 2015), unprecedented pressure has been put on city and municipal water supplies. For example, a recent study by Marks *et al.*, (2020) has shown that the National Water and Sewerage Cooperation (NWSC) only meets 18% of the water demands in Bushenyi Municipality with 56% of the water supply coming from RHRW. Besides, the cost of piped water from NWSC is high with a unit costing 10,566 Shillings (US $ 2.8). Taken together, many homesteads in small towns have resorted to harvesting rainwater to supplement the supply from the NWSC. Unfortunately, the harvested rainwater has been associated with risks of infection and disease outbreaks. Elsewhere, the roof-harvested rainwater (RHRW) is treated before domestic use to ensure it meets the required quality for domestic use (Hamilton *et*

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al., 2019). However, in Uganda, the RHRW is collected directly in water reservoirs and is ready for domestic use. Unfortunately, squirrels, birds, and rats may deposit fecal matter on the rooftops suggesting that the fecal matter of these animals can be washed off the roof surfaces into the water reservoirs during the rainy season. Consequently, the pathogenic bacteria contained within the fecal matter can be washed into the water tanks through the gutters and the water collection pipes when it rains (Kwaadsteniet & Dobrowsky, 2013). Moreover, studies have shown identical biochemical phenotype profiles of *E. coli* isolated from RHWH and the droppings from the rooftops. This implies that the feces were the source of the strains of *E. coli* in water tanks (Ahmed *et al.,* 2015).

The factors influencing the degree of RHRW contamination include but are not limited to:- the organic materials in the gutter, the presence of feces of animals and birds, the volume of water and the retention time of the water in the water tank, roof condition, condition of the water collection pipes and gutters, condition of the storage tank, as well as maintenance and management of the system (Abbasi 2014). Unfortunately, households with rainwater harvesting tanks appear to have insufficient knowledge of water quality safeguard measures and water-related illnesses (Pinfold *et al.*, 2013). Therefore, whereas RHRW may contribute to increasing the available water for domestic use, it may concomitantly increase the risk of transmission of waterborne diseases (Leder *et al.,* 2014). Hence ensuring that the RHRW is of acceptable quality for domestic use remains a big challenge (Zhu *et al.,* 2016). Similarly, a previous study by Baguma *et al.,* (2015) reported a gross lack of awareness of the care for the gutters and water tanks, microbial contamination of RHRW, and the need to divert the first flush.

Although studies elsewhere have investigated the microbial quality of RHRW and the knowledge about the quality of the harvested water, similar studies are scanty in Uganda. The aim of this study therefore was to investigate the quality of RHRW in domestic water reservoirs in Kyengera Town Council, Wakiso District. The results from our study will highlight the need for the implementation of effective and efficient treatment of RHRW before human use. This will help protect the lives of populations using such water for domestic use. Furthermore, the findings of the study will complement the existing body of knowledge that has explored the microbial quality of RHRW. Thomas & Martinson, (2017) have shown that RHRW users lack the information needed to ensure high water quality for home consumption. To assess the knowledge about the quality of roof-harvested rainwater for domestic use and determine the prevalence of coliforms and *E. coli* in roof-harvested rainwater in Kyengera Town Council, Wakiso district.

METHODOLOGY

Study Design

This was a cross-sectional survey conducted in Kyengera town council on the homesteads that performed roof rainwater harvesting between December 2022 and January 2023. Pre-tested, semi-structured questionnaires were used to record the socio-demographic profiles of the homestead head or any responsible person present at the time of sample collection (male or female). In addition, the knowledge the participant had about biological contamination of RHRW was collected. An observation guide was used to record any evidence of contamination.

Study Area

Kyengera Town Council is located within Wakiso District in the central region of Uganda and is part of Kampala metropolitan. Wakiso district covers an area of *241,551 km2* with a population of 1,997,418 people (UBOS, 2017). Wakiso district surrounds Kampala district, the commercial and administrative capital of Uganda, so the majority of the people who work in Kampala reside in Wakiso. Some of the urban parts of Wakiso have been given Municipality status including Nansana, Kira, and Entebbe which comes along with improved services including access to National water. This leaves Kyengera Town Council as one of the fastest developing urban sub-county of the district without a municipality status which compromises service delivery. Kyengera Town Council has a population of 285,400 people and a size of 112.5 km2. Thus, the town Council has 14.3% of the district's total population making it one of the most densely populated areas of the district with a population density of 2,537/km2 (UBOS, 2017). Of the total population within Kyengera's own Council, only 71,767 have access to safe drinking water (25.14%) with the majority of the population (83%) being supplied by spring wells (MOWE, 2022). The laboratory assays were conducted in the microbiology laboratory, at Habib Medical School, Islamic University in Uganda.

Study Population

The study units were the homesteads that practiced harvesting rainwater in Kyengera Town Council.

Sample Size Determination

The sample size, *n*, was calculated using the formula previously described by (Cochran, 1977)

$n =$

P= Prevalence of total coliforms and E coli. A prevalence of 95.7% (Chidamba & Korsten, 2018). was used

Z = Standard normal deviate corresponding to the critical region α (at 5% precision, Z= 1.96)

d = Desired precision

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Thus, a sample size of 252 water samples was predicted. However, due to the low rainfall received during the period of sample collection, a total number of 196 homesteads were recruited in the study.

Sampling Technique

A two-stage sampling was performed. First, simple random sampling was used to recruit parishes and villages in the study. Second, purposive sampling was employed when choosing homesteads that were harvesting rainwater. A sampling frame was developed based on the parishes and villages in Kyengera Town Council.

Sampling Procedure

Out of the 9 parishes, at least one village was randomly selected following the same procedure used to select the parishes. Within each village, 12-34 households proportionate to the number of homesteads that were harvesting rainwater were selected purposively following a systematic transect walk with the guidance of the village health teams (VHTs) and other local leaders. This gave a total of 196 households.

Data Collection Method

The data on the demographic characteristics of the household head, the knowledge about microbial contamination of RHRW, probable sources of contamination, treatment options, and the frequency of cleaning the water tanks were collected by a structured questionnaire. The data on the roof material, water tank material, water gutter material, water tank capacity, duration of water storage, and general cleanliness of the water collection systems were collected by using the observation guide supplemented by photography, with a high-resolution digital camera. Water samples to assess the prevalence of coliforms within the RHRW were obtained by using sterile water collection containers using standard methods. The MacConkey agar was used to culture the total coliforms and observe for growth. The Klinger Iron Agar (KIA) media was used for confirmation of the total coliforms. The Sulphur Indole Motility (SIM) Agar and Kovac's reagent were used for confirmation of *E. coli*.

Data Collection Tools

A structured questionnaire was used to collect the demographic characteristics of the household head. Furthermore, this tool was used to collect the independent variables of knowledge about microbial contamination of RHRW, probable sources of contamination, treatment options, and the frequency of cleaning the water tanks. The observation guide was used to collect the data on the roof material, water tank material, water gutter material, water tank capacity, duration of water storage, and general cleanliness of the water collection systems. A high-resolution digital camera (Techno, 2019) was used to supplement the collection of data by observation. Sterile water collection containers were used to collect samples for evaluation of the prevalence of coliforms and *E. coli* within the RHRW. The MacConkey Agar, Klinger Iron agar, and Sulphur Indole motility Agar were used to grow the coliforms and *E. coli* respectively.

Data Collection Procedure

A pre-tested questionnaire in one community that was not to be included in the study for the research assistants to acclimatize themselves with the questions, seek clarifications, and make content revisions was used. The questions were written in English and were translated orally into Luganda which is the most common local language spoken in Kyengera Town Council. During the survey to collect data, the household head (male or female) was recruited in the study and if the adult head of the household was not available, any other adult member of the household was recruited. In each of the 20 villages, drinking water samples were collected from 20 households with RHRW facilities after the interview. 100ml water samples were taken from the water tank following standard procedures and delivered to the laboratory for evaluation within 6 hours of collection.

Water sample collection procedure

The collection of water from the water tank was done aseptically (*Appendix II*). Briefly, any external fittings from the tap were removed, and the outside of the nozzle of the tap was cleaned. The tap was turned on fully to allow water to run to waste the nozzle for 1 minute. Thereafter, the tap was sterilized by framing and left to cool by running water to waste for 2-3 minutes. Then, hold the sample collection bottle by its bottom in one hand while the other hand is used to remove the cover. The cover was retained in the hands while the bottle was being filled with water with gentle flow and the cap was replaced. The sample was labeled using a waterproof marker with the specimen identification number. The sample was kept on ice in a cool box and delivered to the laboratory for examination.
A total of 196 roof-harvested rainwater samples were collected from different homes in Kyengera Town Council.

Determination of coliforms in roof-harvested rainwater

Media preparation

All the media used in bacterial culture were prepared and cast into sterile plates or test tubes following the manufacturer's instructions. The total coliform count was determined by using MacConkey agar medium, Batch number M081-500G. The determination of *E. coli* was done by using Klinger Iron Agar (KIA), Batch number M078500G. Both of these media were procured from HiMedia Laboratories Pvt Ltd India. Confirmation *of E.*

coli was achieved by using Sulphur Indole Mortality (SIM) agar; Batch number; 610271 was procured from Laboratories Conda SA, Madrid, Spain. The media, plates, and test tubes were sterilized by putting them in an autoclave (XY 280B, China) at 121oC for 15 minutes. After the sterilization process was completed, the medium was cooled to around 40°C. 20mls of the media were poured into the plate or test tube and left for 2 hours to set. For KIA, the test tubes were tilted at an angle to allow the widia to set with a butt and a slope. The laboratory tests were conducted within the Microbiology Laboratory, at Habib Medical School, Islamic University in Uganda.

Pour plating

100µl of RHRW were inoculated on McConkey by spread platting/pour plating to determine the suspected samples to contain total coliforms. After inoculation, the sample was spread uniformly on the media by rotating the plate gently clockwise and anticlockwise with a hand. The plates were then kept in the incubator (Estd 1996 DESCOTM, India) in an inverted position maintained at 37°C overnight. After incubation, the plates were examined for any growth. In case growth was significant, colonial characterization was done to identify the growth of coliforms. Coliforms belong to a group of Lactose-fermenting bacteria and usually grow as pink rose colonies on the MacConkey agar plate. In addition, the number of colonies forming units (CFU) per 100µl of RHRW was enumerated. Finally, the plates were kept at 4-8oC pending biochemical confirmation of the coliforms.

Biochemical testing

The prepared KIA medium (Himedia, M021-500G) in a conical flask was placed in sterile test tubes and the opening of the tube was closed with a cotton gauge. Using a sterile wire loop, the bacterial single pink rose colony was inoculated on the KIA slant by streaking and the butt by stabbing cautiously. In the case of every suspected sample, the same procedure was followed. The KIA test tubes were incubated in an incubator (Estd 1996 DESCOTM, India) at 37°C overnight. The KIA test tubes within an acidic (yellow) slant and an acidic butt with gas were suspected for coliforms.

Determination of prevalence E. coli in roof harvested rainwater

To determine the prevalence of *E. coli* in the sample, a colony from the plate that gave a positive test for coliforms using KIA was inoculated in Sulphur Indole Motility (SIM) agar by stabbing into the medium within the test tube. The tubes were incubated for 24 hours at 37oC and 5 drops of para-amino dimethyl benzaldehyde (Kovacs reagent) were added. *E. coli* is capable of secreting the enzyme tryptophanase that splits tryptophane amino acid in SIM into indole and other products. Indole reacts with para-amino dimethyl benzaldehyde (Kovac's reagent) to give a red ring on top of the media in the test tube.

Study Variables

The dependent variables in this study were; the total coliforms and *E. coli*. The independent variables were: the duration of storage of water, water gutter, duration of water storage, knowledge about microbial contamination of the RHRW, general cleanliness, and frequency of cleaning the water collection systems.

Quality Control

Water samples were collected aseptically following standard procedures. Briefly, the tap was framed for sterility before collection and then given time to cool. Sterile water containers labeled using a waterproof marker were used. Water samples were transported on ice in a cool box and analyzed within 12 hours after sample collection. To test for the validity of the questions, the questionnaire was pre-tested in one community which was excluded from the study. The questions were written in English and translated orally into Luganda for respondents who were uncomfortable with English. Interviews were conducted in the language of choice by the respondent (English or Luganda). Participants who were not able to express themselves in either of the two languages were excluded from the study. Homes without RHRW facilities were also excluded from the study. Participation in the study was voluntary and followed the guidelines of the Helsinki Declaration. Thus, homestead heads who turned down their participation in the study were excluded.

Data Analysis and Presentation

Quantitative data was analyzed by using SPSS version 26.0 and presented in a tabular form using frequencies and percentages for easy interpretation. Bar graphs, box and whisker plots, and pi-charts were used to represent the data.

Ethical Considerations

All the homestead heads who participated in the study gave written informed consent and participation was solely by choice and any head who turned down the consent was free to turn down the participation. Furthermore, the dean of the School of Medicine Habib Medical School, Faculty of Health Sciences, Islamic University in Uganda endorsed the study to be conducted in the Microbiology laboratory

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RESULTS

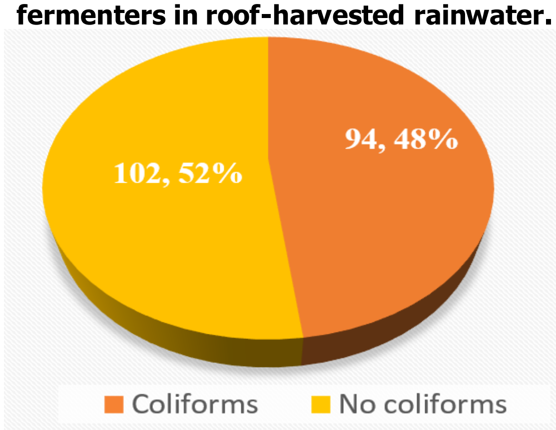
Table 1: Socio-demographic characteristics of the study participants

		N	Marginal Percentage
Gender	Female	80	40.8%
	Male	116	59.2%
Age (years)	19-30	12	6.1%
	30-45	51	26.0%
	46-60	108	55.1%
	over 60	25	12.8%
Education	primary	38	19.4%
	Secondary	50	25.5%
	Above sec	108	55.1%
Household size	above five	148	75.5%
	one to five	48	24.5%
Occupation	Formal	88	44.9%
	None formal	108	55.1%
Years with the tank	less than five years	6	3.1%
	six to ten years	62	31.6%
	over ten years	128	65.3%
Village	Kasenge	12	6.1%
	Katale	24	12.2%
	Kitemu	34	17.3%
	Kyengera	34	17.3%
	Maya	16	8.2%
	Nabingo	20	10.2%
	Nakasozi	26	13.3%
	Namagoma	16	8.2%
	Nansove	14	7.1%
Total		**196**	**100.0%**

From Table 1, Most of the participants were male; 116(52.9%), aged 46-60 years; 108(55.1%) and had education level above secondary; 108(55.1%). Majority had non-formal employment; 108(55.1%), have harvested rain water for over 10 years; 128(65.3%) with most of them having a house hold size of >5 (148; 75.5%). Most of the samples were collected from inhabitants of Kitemu and Kyengera with 17.3% each.

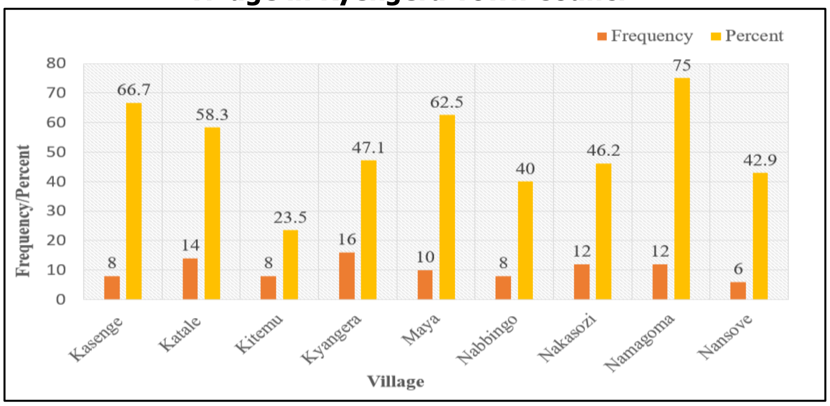
Prevalence of coliforms in roof-harvested rainwater:

Figure 1: Pie chart showing the prevalence of lactose fermenters (coliforms) and non-lactose fermenters in roof-harvested rainwater.



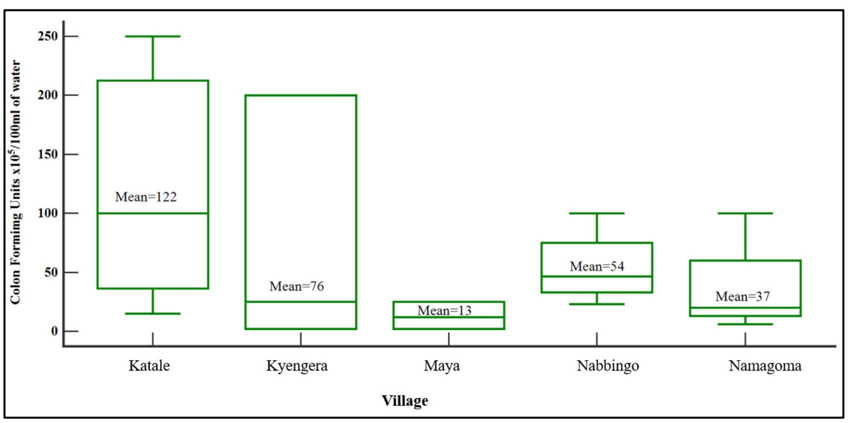
The results have shown that 94 (48.0%) of the samples were suspected to contain total coliforms. The number of colon-forming units ranged from 2 to 250x10^5/mL. The coliforms ferment lactose on MacConkey and appear as pink rose colonies. Representative culture for some of the bacteria that grew. The distribution of coliforms by village in Kyengera Town Council is shown in Figure 2. For further identification of coliforms from suspected samples, a single pink rose colony from each culture plate was picked by using a heat-sterilized wire and inoculated into Klinger Iron Agar (KIA). The KIA agar is a differential medium that can assess the ability of a microbe to ferment lactose, which is used for the identification of coliform bacteria. In KIA, slant coliform only generated gas and the entire media remained acidic (yellow slant and yellow butt) indicating lactose fermentation. In the KIA test, suspected isolates were confirmed as coliform as they showed a specific coliform result.

Figure 2: Bar graph showing the prevalence of coliforms in roof-harvested rainwater by village in Kyengera Town Council.



As presented in Figure 2, Samples collected from Namagoma had proportionately the highest prevalence of coliforms (75.0%%) followed by Kasenge (66.7%) and Maya (62.5%). In contrast, samples collected from Kitemu had the lowest prevalence of coliforms (23.5%) followed by Nabbingo (40.0%).

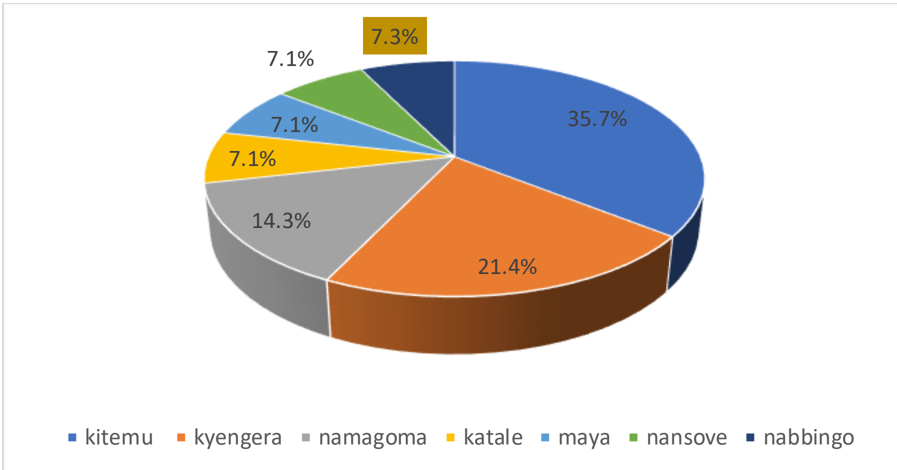
Figure 3: Box and Whisker plot showing the mean colon forming units in roof-harvested rainwater samples for each village sampled in Kyengera Town Council



The mean colon forming units per 100mls varied with the village where the water samples were collected. Thus, Katale had the highest mean colony forming units of 122x10^{5}CFUs (Range=15-250x10^{5}CFUs), followed by Kyengera with a mean of 76x10^{5}CFUs (Range=2-200x10^{5}CFUs), Nabbingo with a mean of 54x10^{5}CFUs (Range=23-100x10^{5}CFUs), Namagoma with a mean of 37x10^{5}CFUs (Range=6-100x10^{5}CFUs) and Maya the least of 13x10^{5}CFUs (Range=2-25x10^{5}CFUs).

Prevalence of E. coli in roof-harvested rainwater samples.

Figure 4: Pie-chart showing the prevalence of E. coli in roof-harvested rainwater samples by village samples in Kyengera Town council



The results have indicated that 7.14% (14/196) of the RHRW samples collected had *E. coli* as demonstrated by the indole test. These were from samples collected mainly from Kitemu with five samples (35.7%), Kyengera with 3 samples (21.4%), Namagoma with two samples (14.3%), Nabbingo with 7.3% and Katale, Maya, and Nansove with one sample (7.1%) each. Furthermore, 92.9% (13/14) of the water tanks whose water had E. coli were from long-lived water harvesters who were reported to have collected water for over 10 years. Finally, 85.7% (12/14) of the water samples with coliforms were sampled from tanks whose owners reported not having cleaned the water tanks before.

Knowledge participants had about the quality of roof-harvested rainwater

As presented in Table 2 below, 109 (96.9%) of the harvesters of rainwater who participated in the study were aware of the influence of RHRW quality on its use as well as the potential contaminants of RHRW. For example, 148(75.5%) of the participants were aware of the role gutter guards play in preventing the items from entering the tank. Similarly, 120 (61.2%) were aware of the role of diverting the first flush as a mitigation against RHRW contamination. Furthermore, 194(99.0%) knew the importance of gutter cleaning in safeguarding the RHRW. Again, 164(83.7%) knew about the water biological contaminants. Further still, 190(96.9%) were aware that water contaminants affect water use. Finally, 140(71.4%) were aware of the use of chemicals in the treatment of the RHRW. Notwithstanding this rich knowledge base, the following gaps have been highlighted by findings from the study which potentially compromise the quality of RHRW. First, there was gross lack access to of information on tank cleaning with 150(76.5%) being naïve about tank cleaning. Second, only 112(57.1%) reported to have at least cleaned the tank. Fortunately, the majority of 36 out of the 84 participants (18.4%) who endeavored to clean the tank did so after the rainy season. Thirdly, the use of water treatment chemicals was practiced by only 38(19.4%) of the participants.

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Table 2: Knowledge participants had on the potential contaminants and treatment options of roof-harvested rainwater

Knowledge statement	Response	Number (%)
Gutter guards prevent items from entering the tank	No	48(24.5)
	Yes	148(75.5)
First flush diverts prevent items from entering the tank	NA	20(10.2)
	No	56(28.6)
	Yes	120(61.2)
Rainwater quality affects water use	No	6(3.1)
	Yes	190(96.9)
Gutter cleaning safeguards drinking water	No	2(1.0)
	Yes	194(99.0)
Access to information on tank cleaning	No	150(76.5)
	Yes	46(23.5)
Have you ever cleaned the tank?	No	112(57.1)
	Yes	84(42.9)
How often do you clean the water tank?	After rain season	36(18.4)
	Never	112(57.1)
	Once a year	18(9.2)
	Twice a year	30(15.3)
Existence of water biological contaminants	No	32(16.3)
	Yes	164(83.7)
RHRW contaminants affect the water use	No	6(3.1)
	Yes	190(96.9)
Existence of water treatment chemicals	No	56(28.6)
	Yes	140(71.4)
Used chemicals to treat roof-harvested rainwater	No	158(80.6)
	Yes	38(19.4)
Source(s) of roof-harvested rainwater contamination	a, b	4(2.0)
	a, b, c	12(6.1)
	a, b, c, d, e	28(14.3)
	a, c	38(19.4)
	a, c	12(6.1)
	a, c, d	32(16.3)
	b, c, d, e	2(1.0)
	c	26(13.3)
	c, d	18(9.2)
	c, d, e	18(9.2)
	c, e	6(3.1)
Method(s) used to treat roof-harvested rainwater	Chlorination, Boiling	2(1.0)
	Chlorination, Boiling, Filtration	14(7.1)
	Chlorination, Boiling, Filtration, Settling	4(2.0)
	Boiling	38(19.4)
	Boiling, Filtration	44(22.4)
	Boiling, Filtration, Settling	60(30.6)
	Filtration, Settling	4(2.0)
	None	30(15.3)
Total		**196(100.0)**

Definition of letters: *- a= air pollution, b= Fecal materials from birds and other animals that stay on the roof and gutters, c=leaves from trees, d=open in let, e=unclean tap*

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Regarding the sources of RHRW contamination, leaves from the trees around the house were reported as the major sources of contamination singly or in combination with other contaminants. As presented in Table 2 above, 26 (13.3%) reported leaves alone as the potential sources of contamination. However, these were also reported along with other contaminants particularly air pollution (38; 19.4%), bird droppings on the roof (12; 6.1%), open-in lets (18; 9.2%) as well as birds dropping and open inlet (32; 16.3%).

Pertaining to the water collection systems and the potential sources of contamination, interesting observations were made. First, 162(82.7%) of the roofs were contaminated with droppings of birds, dirt, or leaves, or a combination of these. Second, 144(73.5%) of the gutters were dirty with evidence of blockage. Third, 126(64.3%) of the gutters had no gutter guards. Fourth, 196(100%) of the water collection system did not have any provision for first flush diversion. Fifth, 140(71.4%) of tap areas were poorly drained with 124(63.3%) evidence of contamination of the tap area.

Table 3: Potential sources of contamination of roof-harvested rainwater as observed from the collections systems for homesteads that harvested rainwater

Source of contamination	Response	Number (%)
Contamination of roof material	No	34(17.3)
	Yes	162(82.7)
Dirty gutters	No	52(26.5)
	Yes	144(73.5)
No gutter guards	No	70(35.7)
	Yes	126(64.3)
First flush system	NA	196(100.0)
Inadequate drainage	No	56(28.6)
	Yes	140(71.4)
Contamination at tap	No	72(36.7)
	Yes	124(63.3)
Total		**196(100.0)**

Fortunately, except for only 30 (15.3%) of the participants in the study, most of the participants reported having used some form of water treatment before domestic consumption. For example, 38(19.4%) boiled the water, 44(22.4%) boiled after filtering the water whereas 60(30.6%) let the eater settle, filtered, and then boiled the water. In contrast, the use of chlorination was rare and if done, it was followed by boiling (n=2, 1.0%), filtration and boiling (n=14, 7.1%), and settling, filtration and boiling (n=4, 2.0%).

Discussion

Prevalence of coliforms in roof-harvested rainwater

The first objective of this study was to determine the prevalence of coliforms in roof-harvested rainwater in Kyengera Town Council, Wakiso district. Data interpretation and analysis revealed the following major findings under this objective. The prevalence of coliforms in roof-harvested rainwater was 48.%. This high prevalence of coliforms is probably because of the contamination of the rooftops with bird droppings. For example, 76(80.9%) of the roofs had visible droppings of the birds with concomitant prevalence of coliforms in the RHRW tanks. This is consistent with the findings by Ahmed *et al.*, (2017). In addition, the adjacent vegetation has been implicated as a potential source of RHRW contamination (Kirs *et al.*, 2017). This is consistent with the findings of this study with leaves reported to be one of the major sources of contamination along with other contaminants.

The coliform prevalence of 48.0% reported in this study is in fair conformity with the prevalence of 52% reported by Ahmed *et al.*, (2015) in *Brisbane City;* Australia among the 50 roof-captured water samples. In another study conducted in Texas, the prevalence of total coliform from 36 RHRW samples was 92% (Bae *et al.*, 2019). In South Africa, the prevalence of total coliforms has been reported from 285 RHRW samples was a prevalence 95.7% (Chidamba & Korsten, 2018).

The differences in the prevalence of the total coliforms reported in the current study and the studies in Australia, Texas, and South Africa can be accounted for by several factors. First, the differences in the roofing materials. Lee *et al.*, (2015) have reported metal roofs to be associated with low microbial load in RHRW despite the associated heavy metal load. Second, wind direction. Hamilton *et al.*, (2017) reported increased microbial load with increased wind speed due to the uplift of organisms from sources and arrival of more organisms to the roof catchment area per unit time. Third, the season for example Daoud *et al.*, (2014) have reported that the bacterial load in RHRW is higher after a long spell of draught. During drought, dust, aerosols, and

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gases from the atmosphere can be directly deposited into the tank through the openings (Hamilton *et al.*, 2017).

The results of this study have also shown that the prevalence of coliforms was related to the years of roof harvesting of water. For example, samples collected from water tanks that had been used for collecting rainwater for over 10 years reported the highest number of coliforms 66 (70.2%). This is associated with continuous accumulation of debris, organic matter, and fecal dropping as a result of irregular or no cleaning of the tank consistent with the findings by Hamilton *et al.*,(2017). Besides, 112(57.1%) of the participants in the current study had never cleaned the RHRW tank by the time of sampling. This finding is not surprising. For example, Ahmed *et al.*, (2017) reported that 92% of RHRW tanks had never been cleared in an Australian study.

The prevalence of coliforms indicates contamination of roof harvested rain water and therefore compromised quality for home use when untreated. Indeed, according to the World Health Organization (WHO), there should be zero coliforms in drinking water. The findings of this study therefore suggest that the roof-harvested rainwater collected from Kyengera Town Council is grossly contaminated with coliforms. This does not only pose a risk of contracting water-borne diarrheal diseases but may also be a source of antibiotic resistance in this community. Thus, immediate interventions to mitigate the transmission of waterborne diarrhea in this community are needed. For example, the use of health massages to avoid contamination of the RHRW water, provision of treatment options like chemicals (water guard) as well as reducing the cost of piped water from National water supplies among others are warranted.

Prevalence of E. coli in roof-harvested rainwater samples

The second objective of this study was to determine the prevalence of *E. coli* in roof-harvested rainwater samples in Kyengera Town Council, Wakiso district. Data interpretation and analysis revealed the following major findings under this objective. The prevalence of *E. coli* in roof-harvested rainwater collected from Kyengera Town Council was 7.14%. The high prevalence of *E. coli* can be attributable to the visible bird droppings reported in 80.9% of the homesteads from which the water was collected consistent with the findings by Ahmed *et al.*, (2017).

The prevalence of *E. coli* reported in this study is much lower than the prevalence of 62% reported from 80 RHRW tanks in South Africa by Dobrowsky *et al.*, (2013), 64% reported from 14 RHRW tanks in the USA among American Samoa (Kirs *et al.*, 2017), 68% reported by Hamilton *et al.*, (2016) from 134 RHRW samples collected from Southeastern Queensland and 24% from 92 RHRW reported by Leong *et al.*, (2017) in Malaysia.

The differences in the prevalence of *E. coli* reported in the current study and the aforementioned studies can be accounted for by several factors;

Firstly, the studies in South Africa, USA American Samoa, and Southeastern Queensland, Australia used the membrane filtration method to determine the prevalence of *E. coli* in RHRW. On the other hand, the current and the Malaysian studies used the spread plate method. The membrane filtration method is more sensitive than the spread plate method (Nurliyana *et al.*, 2018).

Second, the relative importance of the potential sources of RHRW contamination. In Australia, the Possum (tree-dwelling Australian Marsupial) has been implicated and these are absent elsewhere (Ahmed *et al.*, 2016).

Third, the differences in the seasonality with extremes of temperatures in summer and winter. The RHRW samples collected in summer have been reported to have more *E. coli* than those collected in winter. For example, Jordan *et al.*, (2018) sampled 11 RHRW tanks in summer and in winter. The prevalence of *E. coli* decreased from 27% in summer to 0% in winter. The samples from RHRW tanks collected in South Africa, USA, Australia, and Malaysia were probably collected during summer and this could have given the high prevalence of *E. coli* reported by the respective studies. Fourth, the roofing materials have been reported to influence the *E. coli* concentration in the RHRW tanks. For example, Lee *et al.*, (2015) reported that metal roofing materials were the best for the collection of RHRW due to low levels of *E. coli* in water reservoirs that have captured water from metal roofs. The roofing materials for the RHRW samples used in the current study were mainly metal type partly explaining the low prevalence of *E. coli* reported in this study as opposed to the studies in South Africa, the USA, Australia, and Malaysia where roofs are probably made up other materials like fiberglass, concrete tile, singles, galvalume metal and green roofs.

Finally, meteorological parameters have been allied with differential *E. coli* load in RHRW tanks. Hamilton *et al.*, (2017) showed that longer dry periods were associated with higher *E. coli* counts in RHRW because of the accumulation of debris, fecal dropping, and organic matter on the roof.

According to the drinking water guidelines by the World Health Organization (WHO), *E. coli* should not be detected in 100mL of drinking water and if detected, immediate action should be taken to minimize human health risks (Ahmed & Toze, 2014). Besides, Chidamba & Korsten, (2018) have shown that *E. coli* is short-lived in stored RHRW compared to other coliforms like *Enterococcus*. Thus, the high prevalence of *E. coli* observed in this study suggests a recent contamination of the RHRW. The *E. coli* are commonly found in the feces of birds which are dropped on the roofs of the buildings causing the contamination of the water (Ahmed *et al.*, 2015).

The high prevalence of *E. coli* and other fecal coliforms reported in the current study and other studies from the

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literature poses an epidemiological challenge to *E. coli-borne* diarrheal diseases in local communities. This can be exacerbated by not only the increasing water costs but also the inadequate supply of water by the national water supply systems which has prompted the local communities to harvest rainwater for domestic use. Therefore, in light of the study findings, there is an urgent need to increase the supply of water to local communities at a subsidized cost. Alternatively, the local health authorities should provide RHRW treatment options to mitigate infections with diarrheal diseases.

Knowledge participants had about the quality of roof-harvested rainwater

The third objective of this study was to assess the knowledge participants had about the quality of roof-harvested rainwater for domestic use in Kyengera Town Council, Wakiso district. Data interpretation and analysis revealed the following major findings under this objective. Over 96% of the participants knew the influence of contaminants on roof-harvested rainwater quality and its use. The high awareness of roof-harvested rainwater contamination and the potential health threat of the contaminants is attributable to the high education standards reported by the participants in the study. Over 55% of the participants had education above secondary school and over 25% attained secondary education.

The high knowledge base regarding roof-harvested rainwater contamination and the potential health risks associated with consuming contaminated water has been reported by Baguma *et al.*, (2015). They reported an awareness of 84% regarding biological contamination of RHRW and potential risks associated with its consumption. The slight difference between the previous study and the current study can be attributed to the differences in the education levels of the respondents used in the two studies. In the current study, 55.1% of the participants had education above secondary school whereas only 14.2% of the participants had attained a comparable level of education in the study by Baguma *et al.*, (2015).

Whereas over 60% of the study participants knew the role of first flush divers, gutter guards, and their regular cleaning in ensuring RHRW safety for domestic use, the implementation of these measures was low. For example, 57% of the study participants reported never to have cleaned the water tank. This can be attributed to results from the findings and the literature. For example, over 76% of the study participants denied having access to information concerning tank cleaning. This finding is consistent with the report by Hamilton *et al.*, (2017) and Ahmed *et al.*, (2015) who reported a gross lack of access to information about RHRW quality management. In line with the findings from the study and those reported by studies from the literature, there is a need to disseminate information to RHRW users in areas of frequent gutter and tank cleaning.

Conclusion

The study primarily sought to understand the prevalence of *E. coli* and other coliforms in roof-harvested rainwater. In addition, the study also wanted to establish the knowledge users of roof-harvested water had about the potential contaminant of the water. The study established that there was gross contamination of the roof-harvested rainwater collected within Kyengera town council with *E. coli* and other coliforms. Moreover, the users of the roof-harvested rainwater were aware of the biological contamination of the water they harvested. Given the findings, the consumption of coliform-contaminated roof-harvested rainwater will continue in this community. This is because, despite the awareness of the contamination, the members are adamant about implementing water treatment and hygiene alternatives that are economically viable at the household level like first flush divers, chemical treatment, and tank and gutter cleaning among others.

Study limitations

The failure of some roof-harvested rainwater (RHRW) collectors to participate in the study and the limited geographical scope were the potential limitations of the study. The prolonged drought during data collection limited the number of samples for use in the analysis.

Recommendations

Three key recommendations can be made from the findings of this research report. First, the prevalence of coliforms in the roof-harvested rainwater samples is a marker of warm-blooded animal fecal contamination. Second, it should be obligatory to treat the roof-harvested rainwater at the household level to mitigate the transmission of water-borne diarrheal diseases. Finally, health education should be implemented at the community level to increase community awareness about the dangers associated with the consumption of coliform-contaminated roof-harvested rainwater.

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List Of Abbreviations And Acronyms

BGLB: Brilliant Green Lactose Bile
CFU: Colony Forming Units
DAEC: Diffusely Adherent E. coli
DEC: Diarrheagenic E coli
EAEC: Enteroaggregative E. coli
EC: Escherichia coli
EHEC: Enterohaemorrhagic E coli
EIEC: Entero-invasive E coli
EPEC: Enteropathogenic E. coli
ETEC: Enterotoxigenic E coli
ExPEC: Extra Intestinal Pathogenic E coli
FIB: Fecal Indicator Bacteria
InPEC: Intestinal Pathogenic E. coli
LST: Lauryl Sulfate Tryptose
MPN: Most Probable Number
NMEC: Neonatal Meningitis Escherichia coli
NWSC: National Water and Sewerage Cooperation
RHRW: Roof-Harvested Rain Water (RHRW)
SSA: sub-Saharan Africa
UBOS: Uganda Bureau of Statistics
UNICEF: United Nations Children's Fund
UPEC: Uropathogenic E coli
UTI: Urinary Tract Infection
VHTs: Village Health Teams
WASH: Water Sanitation and Hygiene
WHO: World Health Organization

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