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Assessment of physical conditions and proposed best management practices of domestic storage tanks supplied by a water utility in a rapidly growing City

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ABSTRACT

The physical conditions of domestic storage tanks for customers supplied by a water utility were assessed in Kampala, a rapidly growing City in Uganda. A longitudinal assessment of 372 storage tanks in 6 sampled administrative Wards with a minimum of 6 samples collected from each site in both wet (March-May) and dry (June-August) months of 2017 was carried out. A set of guiding questions were used to establish tank conditions with a YES or NO response and a range of low to critical risk rating. It was revealed that there was a statistically significant relationship (p=0.001) between tank physical conditions and quality of stored water. Two of six Wards in the City had high levels of water contamination related to domestic water storage tanks with poor sanitary conditions and contaminated water with E. coli. The study therefore revealed that the physical conditions and management of domestic water storage tanks have an effect on water quality. This is important information for a water utility as it means that it is not enough to supply safe water if the quality may deteriorate upon storage at the consumer premises. A routine inspection checklist and consumer guidelines for domestic storage tank management are proposed.

Keywords: Conditions, contamination, storage, tank, utility, water.

INTRODUCTION

Worldwide, water supply systems include storage facilities. However, storage facilities were originally developed for hydraulic system operation and not water quality (Kirmeyer, 1999). Many cities in developing countries are still faced with water supply problems. Intermittent water supply has led some households to install water storage tanks to respond to water breaks (Malanda & Louzolo-Kimbembe, 2014), meaning that water utility customers use water storage facilities like overhead tanks to ensure reliable continuous water supply on their premises.

The US Environmental Protection Agency (EPA) (2002), has argued that despite the installation of water storage tanks, challenges still encountered involve excessive water age, sediment accumulation and loss of disinfectant residual. Similarly, the WHO

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(2017), reported that unsafe water for consumption still exists in storage facilities in the various parts of the world.

The cause of unsafe water in storage facilities has been majorly due to the deficiency in monitoring and management. A study by Craun et al. (2002) in the United States of America (USA) showed that one of the major causes of unsafe water, during water borne disease outbreaks, was distribution system infrastructure deficiencies. Another similar study by Clark et al. (1996), in Gideon, Missouri, documented that a *Salmonella typhimurium* outbreak was due to birds' droppings contamination of a municipal water storage tank. In developing countries, drinking water contaminations are most often due to deteriorated water distribution and storage infrastructure (Chalchisa, Megersa and Beyene, 2017).

According to the Ministry of Water and Environment (MWE) Sector Performance Report 2017, only 72% of this infrastructure is managed in urban Uganda (MWE, 2017). Studies have revealed that water storage tanks have their own impact on quality of water if not properly managed in hygienic ways such as routine cleaning and covering of openings (EPA, 2002; Levy et al., 2008; Schafer and Mihelcic, 2012; Chalchisa et al., 2017). Akuffo et al. (2013) and McLarnan (2017) reported the re-growth of bacteria in water stored during a short or long periods. The bacteria re-growth is especially as a result of high temperatures and low disinfectant residual. For instance, Akuffo et al. (2013) recorded up to 250 CFU/100 mL of FC from water storage tanks in Ghana.

Kampala city in Uganda, a rapidly growing City in the developing world is also faced with the challenge of water quality. Recently, there was an outbreak of typhoid fever in Kampala city (WHO, 2015). The outbreak was linked to the compromised water quality due to reasons including intrusion of contaminants into premise plumbing, mixing of distribution system water with groundwater, or contamination of water during storage in tanks (Murphy et al., 2017).

Cross-contamination in the distribution system and unsafe storage are some of the major sources of water borne diseases (WHO, 2011), but they are mostly overlooked by water professionals. Additionally, most of the storage facilities used in Uganda for domestic water storage are usually located in sites such as roof tops, ceilings, overhead stands and underground. This makes their monitoring, inspection, and maintenance difficult.

Furthermore, it has been reported by EPA (2002) that sanitary conditions such as the presence of sediments, biological growth, and floatable debris/insects in the tank, rodent or bird activity on and around the tank can compromise the quality of water. As such, the quality of water in these storage facilities is questionable since the water utility (National Water and Sewerage Corporation (NWSC)) mandate does not involve monitoring customer's water storage tanks (Water Act, 2000).

In 2015, like in other previous years, NWSC received numerous complaints about contaminated water from its customers, especially those who had domestic storage tanks in Kampala. Over 80% of the water quality complaints raised were of water from storage tanks (NWSC, 2015a). It is therefore important to assess the water quality, tank conditions and contamination levels of domestic water storage tanks of a water utility in a rapidly growing city in the developing world. The study therefore assessed the contamination levels and suggested the best management practices of domestic water storage tanks for NWSC Customers in the Central division of Kampala city.

MATERIALS AND METHODS

Study area

The study was conducted in Kampala District, Kampala capital city, in the Central Division. According to MCHG (2004), Kampala is the Capital city of Uganda that is located in the central region of the country and covers a surface area of 195 square kilometres (Figure 1). The city consists of five Divisions; Central, Kawempe, Makindye, Lubaga and Nakawa.

Study design

A longitudinal assessment of water quality among 372 storage tanks/households in

6 sampled Wards in Kampala District was conducted between March and August 2017. A minimum of 6 samples were collected from each site in both wet (March-May) and dry (June-August) months (UNMA, 2016; World Bank, 2016). Sampling was done weekly, with an average of 17 samples picked each day until 62 samples were obtained from each Ward every month for the dry and wet seasons. March, April and May (18-28 °C; 130-175 mm rainfall) were considered as wet months and June, July and August (16-25 °C; 46-86 mm rainfall) as dry months (UNMA, 2016; World Bank, 2016). This was in order to monitor the impacts due to a change in season on the water in storage tanks.

Population and sampling techniques

The study was conducted in the six Wards of the Central Division of Kampala City, Uganda. Kampala City, a rapidly growing city in a developing country was a good representative of any city in the world (Kulabako et al., 2010). The Central Division (Figure 2) comprises of Central Business District commercial areas, up-scale residential areas, and slums, a combination that is common with most developing country cities in the world. The Central Division also had the most number of NWSC customers with water connections, and had registered the most complaints about questionable quality of water at their premises (NWSC, 2015c; NWSC, 2016). As at June 2016, the Central Division had the highest number (2,570 or 28%) of the water connections in Kampala City. 69% (1,897) of the Central Division connections had domestic water storage tanks (NWSC, 2016).

A preliminary study was conducted to identify buildings/NWSC customers that had a domestic water storage tank of more than two years old in use in each Ward. This period was assumed to be adequate for tank conditions to cause water deterioration, if any, in the storage tanks. Only NWSC customer tanks were considered.

Krejcie and Morgan tables for sample size determination was used to determine the sample size (Krejcie and Morgan, 1970) with $p = 0.05$; where the probability of committing type I error is less than 5% or $p < 0.05$. There were 1,897 NWSC customer connections in the study area, but the 11,856 water connections in Kampala City Centre were taken as the population size (N), giving 372 connections as the sample size (S) from Krejcie and Morgan tables (320 plus 50 additional connections as a factor of safety). Cluster random sampling was used where the whole geographical population was divided into clusters (Wards). A random sample from each cluster of 62 NWSC customers was performed (Wilson, 2010). This was according to whether the customer had a water storage tank, accessibility and willingness to participate. This sample size was considered statistically significant and representative of NWSC customers in the study area and useful in drawing correct conclusions (Krejcie and Morgan, 1970). At a confidence level of 95% with an error of 0.05, the sample size gave valid and reliable results for a generalized population.

Study Variables

The study considered the following variables (Table 1).

Data collection

Water quality

All samples were tested for physical, chemical and bacteriological properties. Each tank was assessed for various characteristics (tank type, location, age, cleaning frequency in a year, either its covered, cracked or leaking, presence of birds' faecal matter, algal growth and rusty or sludge). This was to determine whether the various characteristics of the tanks had an effect on water quality based on the drinking water Standards (Uganda Standards, 2014) and Guidelines (WHO, 2017). 250 mL Pyrex glass bottles were used for samples of bacteriological parameters and 200 mL plastic bottles were for physicochemical parameters. All containers were prepared as outlined in the NWSC Standard Operating Procedures (NWSC, 2015b).

Sampling, and transportation of samples, was done in accordance with the recommended protocols as outlined by Standard Methods for the Examination of

Water and Wastewater by APHA (2017). Samples were picked from the water storage tanks using a previously sterilized deep sampler. A reference sample of Inflow water from NWSC was also picked alongside (this was not done consistently, but the monthly NWSC water quality results for a study period have been compared to the study findings for statistical comparisons –Table 2). Turbidity, pH, temperature, free and total chlorine were measured onsite as they could change during transportation.

The laboratory experimental work involved determination of physical, chemical and bacteriological parameters of water samples using methods described in the APHA, AWWA and WEF joint publication, "Standard Methods for the Examination of Water and Wastewater" (APHA, 2017).

Turbidity was measured using a handheld turbidimeter (HACH 2100Q with ± 2% of reading plus stray light accuracy), while Free and Total Chlorine were determined using a pocket colorimeter (HACH, Pocket Colorimeter™ II with ± 2 nm wavelength accuracy), DPD and 1% Potassium Iodide (KI) solution respectively. Electrical Conductivity (EC), Temperature and pH were measured using a multi-meter probe (HACH, HQ30D Portable Meter with 0.5 µS/cm, ±0.3 °C and 0.002 pH accuracies respectively). Faecal and Total Coliform counts of the water were determined by membrane filtration with sodium lauryl sulphate broth technique with 47mm diameter, 0.45µm pore size cellulose ester membrane filters incubated at 44 °C and 37 °C for 18 hours for Faecal and Total Coliforms respectively, and results were reported as CFU/100mL (NWSC, 2015b; Rice et al., 2017). For determining the presence of *E. coli* bacteria, *E. coli* agar was used and the same procedure as above was followed with incubation at 37 °C for 18 hours (NWSC, 2015b; Rice et al., 2017).

Association between tank conditions and water quality

A sanitary survey was conducted on each domestic water storage tank to ascertain its physical condition. Seven guiding questions were used to assess sanitary conditions, each carried a maximum risk effect weight of 10.

A *chi*-square test of independence was used to assess the degree of association between study variables while the factors associated with poor quality of water were analysed using multivariate logistic regression model. A p-value of less than 0.05 was considered to be statistically significant in this study.

Data collection instruments

A Data Collection Sheet (DCS) was used to gather information such as; sample point Code, Division, Ward, GPS coordinates and weather conditions, time of sampling, physical, chemical and bacteriological parameters of the water sample.

A Sanitary Inspection Form (SIF) was used to gather information about cleaning frequency, tank age, tank material, and location of the domestic water storage tanks. The SIF also captured the tank conditions of the storage tanks such as; the presence of sediments, biological growth, floatable debris and insects in the tank, rodent or bird activity on and around the tank. For each domestic water storage tank, a set of guiding questions were used to establish tank conditions with a YES and NO response.

Quality/error control

The pre-test of data collection tools on tank conditions was done on a small number of respondents (6 samples from each Ward) for the establishing accuracy of questions and responses, clarity and ease of comprehension, redundancies, omissions and feasibility of implementation. The results of the pre-test helped to refine the data collection instruments to establish their validity and reliability in gathering required information.

Data analysis

All data analyses were done in STATA software version 13.0 (StataCorp, 2013), and ArcGIS software version 10.2.1 was used in geostatistical analysis (ESRI, 2014).

Data was analysed using the Statistics and Data (STATA) analysis package to determine frequencies, percentages, and the relationships between the various variables. The gathered data was coded into themes before analysis and discussion of the content. A causal analysis concerned with how one variable affects changes in another variable (Kothari, 2004), was used to determine how tank conditions affected water quality in the domestic water storage tanks, one of the research questions. A *chi*-square test of independence was then carried out to assess the degree of association between these variables. Data for electrical conductivity, temperature and total chlorine were not included for analysis as they all met the WHO Guidelines (2017) and Uganda Standards (2014) for drinking water.

Ethical considerations

Permission to conduct research was given by NWSC. Special codes were used to anonymize identity of customers for confidentiality purposes. Customers provided informed consent and their anonymity was observed according to Cohen et al. (2011).

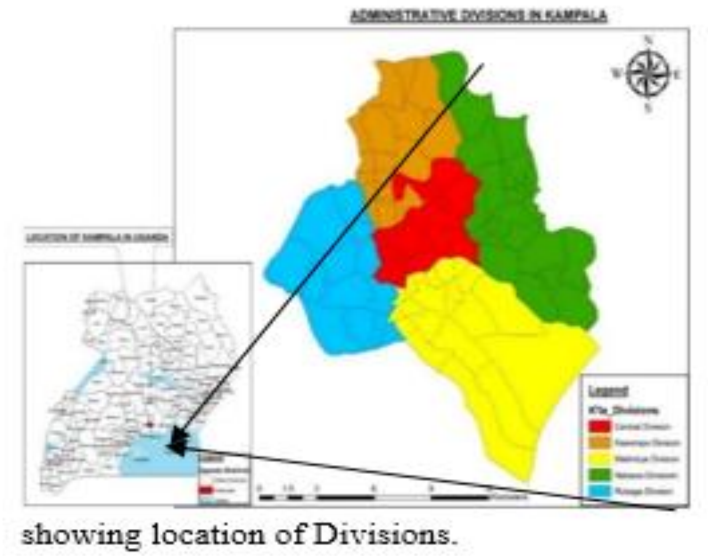

Figure 1: Map of the Study Area in Uganda showing location of Divisions.

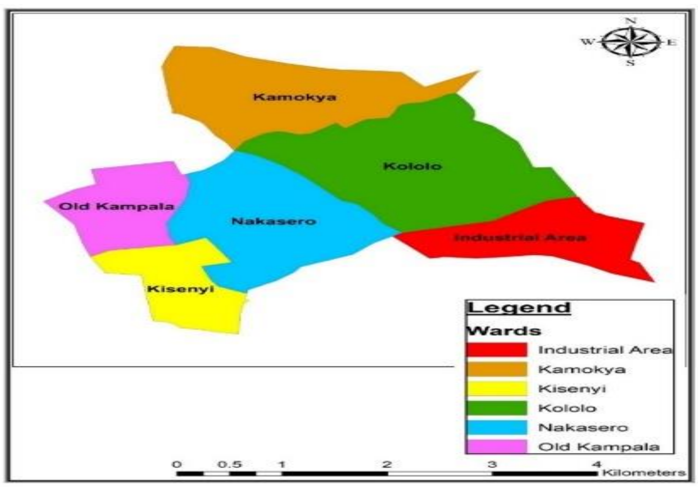

Figure 2: Map of the Study Area in Central Division. Source: Adapted from NWSC (2017).

Table 1: Study Variables.

Variables		Measurement (Unit)	Indicator (Howard and Bartram, 2003; Uganda Standards (US), 2014; WHO, 2017)
Dependent	**Water Quality** (Physical-Chemical and Bacteriological Parameters)	Temperature (°C)	<25
		Electrical Conductivity (µS/cm)	≤1500
		pH (- -)	6.5-8.5
		Turbidity (NTU)	≤5
		Free Chlorine (mg/L)	≥0.2-<0.5
		Total Chlorine (mg/L)	≤5
		Total Coliforms (CFU/100mL)	0
		Faecal Coliforms (CFU/100mL)	0
		Escherichia coli (CFU/100mL)	0
Independent	**Tank Conditions**	Tank Type	Plastic/ Concrete/Metallic
		Algal growth (Presence)	Yes/No
		Rusty (Presence)	Yes/No
		Cleaning frequency in a year (Number)	0-<12
Intervening		Covered (Presence of a lid)	Yes/No
		Cracked Tank	Yes/No
		Age of Tank (Number in years)	≥2
		Location of the Tank	Elevated/Ground/Underground
		Birds' faecal matter (Presence)	Yes/No
		Leaking (Presence)	Yes/No
		Algal growth (Presence)	Yes/No
		Rusty (Presence)	Yes/No
		Inflow water from NWSC pipeline	Meets Uganda Standards and WHO Guidelines for drinking water
		Change in season (In a year)	Wet/Dry

Table 2: Water quality by tank condition of the domestic water storage tanks.

Sanitary Condition (n =372)		Water Quality Conforms to standards				p - value
		Yes		No		
		Number	%	Number	%	
Type of tank	Concrete	23	92	2	8	0.001*
	Metallic	8	44	10	56	
	Plastic	279	85	50	15	
Position of tank	Elevated	257	82	55	18	0.279
	Ground	32	84	6	16	
	Underground	21	94	1	5	
Age of the tank	0 - 5	133	86	21	14	0.019*
	5 - 10	88	88	12	12	
	>10 years	89	75	29	25	
Cleaning frequency	Never	196	77	60	23	0.001*
	Once a year	102	98	2	2	
	More than once	12	100	0	0	
Cracked	No	306	85	54	15	0.001*
	Yes	4	33	8	67	
Leaking	No	303	85	52	15	0.001*
	Yes	7	41	10	59	
Covered	No	4	9	39	91	0.001*
	Yes	306	93	23	**7**	
Presence of algae	No	238	97	9	3	0.001*
	Yes	72	58	53	42	
Rust or Sludge	No	122	97	4	3	0.001*
	Yes	188	76	58	24	

NB: *Significant level, p<0.05. Conforms, Yes or No, to Standards (Uganda Standards, 2014) and Guidelines (WHO, 2017) for drinking water. Samples within the Wet months were considered in generating this composite variable.

RESULTS AND DISCUSSION

In this study, a total of 372 (n=372) samples were picked, with 62 samples from each of the six Wards of commercial, planned residential settlements (Kololo, Nakasero, Old Kampala, Kamwokya) and those with unplanned, industrial settlement patterns (Kisenyi, Industrial Area).

Association between tank conditions and water quality

Tank conditions of the storage tanks

Study findings (Figure 3) revealed that most tanks were made of plastic (88%), elevated (84%), below 5 years old (41%) and not cleaned (69%). A similar study by Aish (2013) showed that plastic tanks are frequently used for domestic water storage. Plastic water tanks are perceived to be durable, safe, and cost-effective and easily available in a wide range of sizes. Most tanks are elevated because domestic water storage tanks are used to maintain the pressure and act as a reservoir during interruptions in supply (EPA, 2002).

The study findings revealed that most of the tanks had rust/sludge (66%), 3% were cracked, 5% were leaking and 12% were not covered while 34% of them had the presence of algal growth. This was a clear indicator that most tanks had not been often monitored and cleaned. WHO (2013) noted that poor handling and management of household water facilities contributed to the contamination of water.

Physical conditions of the water storage tanks and water quality

The study showed that there is an influence of the tank material, presence of algae/ rust/sludge, cleaning frequency, cracked, leaking and uncovered tanks on water quality, whereas the age and position of the tank was not significant (p=0.019 and p=0.279 respectively) (Table 2). Tank characteristics and conditions are affected by the routine management of the tanks and not their age or positions confirming a similar study by Schafer and Mihelcic (2012).

Further, only 9 (3%) of the tanks without algae compared to 53 (42%) of those with algae had water with poor quality, not meeting the Uganda Standards (2014) and WHO Guidelines (2017) for drinking water (Table 2). There was a statistically significant association (p = 0.001) between presence of algae and water quality. Bacteria re-growth is known to impact on disinfectant residual (Duer, 2016), thus the impact of algae on water quality. The study findings further indicated that there is a strong linkage between bacteriological water quality (total coliforms and *E. coli*) and water storage sanitation. This association was also established in a study by Lukubye and Andama (2017).

This study found out that 56% of metallic tanks, 8% of concrete tanks and 15% of plastic tanks had water not conforming to the Uganda Standards (2014) and WHO Guidelines (WHO, 2017) for drinking water. This may be due to the corrosive effect of chlorine on metallic tanks. The US Environmental Protection Agency (EPA, 2002), argues that maintaining water quality in storage facilities is a serious challenge due to factors such sediment accumulation and loss of disinfectant residual.

It was also established by this study that tanks that have never been cleaned 60 (23%) have the highest likelihood of having contaminated water (p = 0.001) because the accumulated sludge affects physical, chemical and bacteriological characteristics of water with an increase in turbidity levels, rapid depreciation of residual chlorine and a favourable breeding environment for algae (Moyo et al., 2004; Schafer and Mihelcic, 2012).

Additionally, 91% of uncovered tanks had water not had conforming to the expected standards (Uganda Standards, 2014) and WHO Guidelines (WHO, 2017) for drinking water. The uncovered tanks provided entry for foreign matter into the water such as birds' faeces that contributed organic matter. A similar study by Johnson et al. (2016) in Lalo Commune, Benin revealed that birds' droppings in water was a major contamination factor to potable water in storage tanks. This was also reported by Schafer and Mihelcic (2012) and Thompson et al. (2003) that cleaning frequency and presence of human or animal faeces were the main contributing factors for compromised water quality.

Suggested consumer storage tank best management practices (BMPs)

In order to ensure drinking water quality that meets the drinking water standards/guidelines at the consumer point, adequate and appropriate monitoring and maintenance of water storage facilities/tanks is required. Below are extracts of suggested tools and best management practices for proper customer storage tank management developed from the study observations and results.

Monitoring tools

Tables 3, 4, 5 and 6 present the daily, weekly, monthly and quarterly duties respectively by owner, responsible person/technician/entity.

Inspection protocol

Table 4 *present the inspection* protocol.

Risk prediction checklist

Table 5 present the risk prediction checklist.

Study limitations

It was not possible to view clearly inside every elevated storage tank which may have resulted in underreporting likely sanitary conditions of storage tanks.

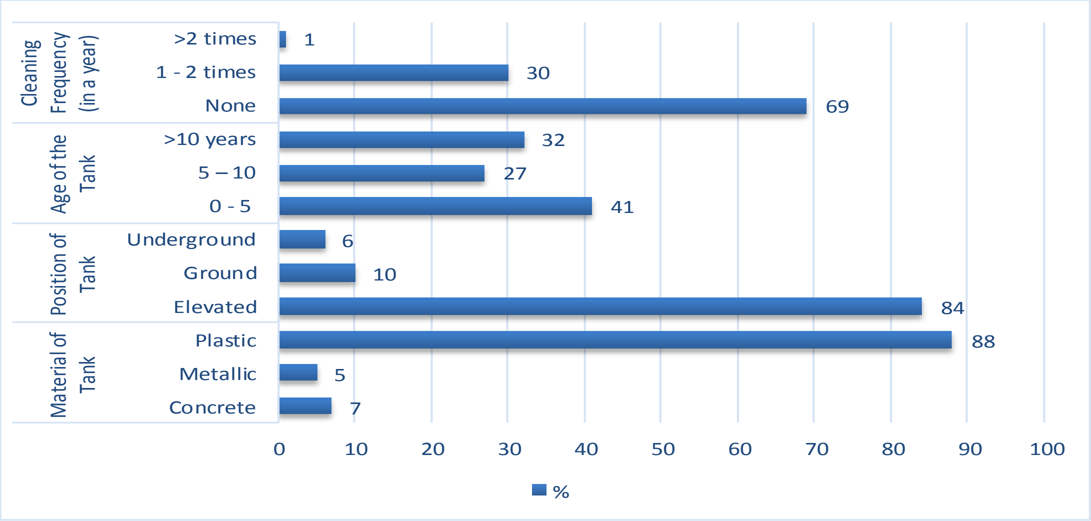

Figure 1: Cleaning Frequency, Location, Material and Age of the Storage Tanks in percentages.

Table 6: Daily Duties (By Owner, Responsible Person).

DAILY CHECKLIST			
Date: …………………… **Check**	**Response**	**Possible Cause**	**Corrective Action Taken by Owner/Responsible Person**
Is the tank overflowing?	Yes ☐ No ☐		
Is the tank leaking?	Yes ☐ No ☐		
Is water level within the required range?	Yes ☐ No ☐		
Are the warning lights in normal operating mode?	Yes ☐ No ☐		

Table 7: Weekly Duties (By Owner, Responsible Person/Technician).

WEEKLY CHECKLIST Date: …………………………				
No	**Defects Check**	**Nature of defect**	**Repairs Done**	**By Who**
1				
2				
3				
Comments:				

Table 8: Monthly Duties (By Owner, Responsible Person/Technician/Entity).

MONTHLY CHECKLIST Date: …………………………					
Water Quality Check					
#	**Water Level (m^3)**	**No of samples**	**Analysis needed**	**Parameters for analysis:** Bacteria (**B**)	**Sample Analysis Lab Name** ………………………………
1					
2					**Certified for potable water**

Table 9: Quarterly Duties (Owner, Technical/Responsible Person/Entity).

QUARTERLY INSPECTION REPORTING			
Inspection By (Owner, Technical/Responsible Person/Entity):………………………………………………		**Inspection Date:** ………………..	
Sanitary Inspection Checklist	**Was examination performed?**	**Inspection Results**	
		Unsanitary Condition	**Corrective Action Taken**
Examine all tank openings (if any) such as vents, overflows) if they are properly screened.	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
Examine for blockage or tears of vents and screens	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
Examine for any deterioration in the tank walls or	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐

Table 10: Inspection protocol.

GENERAL INFORMATION		
Area:		
Contact Person:	Address:	
Tank ID:		
Tank Location:	Tank Material:	
Tank Age:		
Building Occupancy: ☐ Multiple Dwelling ☐ Commercial ☐ Mixed Use ☐ Other:		
INSPECTION REPORTING		
Was a tank inspection performed? ☐ Yes ☐ No	**Inspection By** (Person, Entity/firm):	**Inspection Date:** ....
Sanitary Inspection	**Was examination**	**Inspection Results**

Table 11: Risk prediction checklist.

GENERAL INFORMATION		
Area:		
Tank Name:	Tank ID:	
Tank Location: Tank Material:		
Tank Age:		
Proposed Checking Date:	Actual Checking Date:	
Name of Person Checking:	Title of Person Checking:	
I certify that this information is complete and accurate:	Date:	
OVERALL TANK CONDITION		
Risk Check	**Response**	**Risk Score**
Is the tank covered?	Yes ☐ No ☐	

Conclusion

The study showed that most of the tanks in the study area were plastic (88%), elevated (84%), and below 5 years old (41%). 69% of the domestic water storage tanks were not cleaned, 3% of the tanks were cracked, 5% were leaking, 12% were not covered, 34% had algal growth, and 66% had rust or sludge. There was an impact (p=0.001) of tank conditions on water quality in domestic water storage tanks. Tanks cleaned more than once in a year had all (100%) their samples conforming to Uganda Standards and WHO Guidelines for drinking water. Properly managed tank conditions produced water of good quality. Wards with unplanned and industrial settlements had highest number of tanks with contaminated water levels. The study therefore established that tank conditions of domestic water storage tanks for Customers of a water utility had an effect on the water quality, causing it not to meet the required Uganda Standards and WHO Guidelines for drinking water under certain conditions. Hence, regular multi-level maintenance and routine water quality checks following proposed best management practices should be done.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

All authors participated in the project design, data collection and data analysis. They produced and approved the final submitted manuscript.

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