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Assessment of Drinking Water Quality Management and a Treatment Feasibility Study for Brick by Brick Water Storage Tanks in Rakai Uganda

by

James V. Murduca

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Civil Engineering
Department of Civil and Environmental Engineering
College of Engineering
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Keywords: Rainwater Quality, Self Supply, Pathogen, Microbial Contamination, Sustainability, International Development, Chulli System, Sustainable Development Goals

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DEDICATION

"Without science there can be no morality" - Lawrence Maxwell Krauss

"Oh yes, the past can hurt. But the way I see it, you can either run from it, or learn from it." –Rafiki, *The Lion King* (1994)

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First and foremost, I would like to thank my family including my mom (Lauren Murduca), dad (James Murduca), and sister (Leigh Ann Murduca) for supporting me through every step of this process from leaving New Jersey to completing this project. I would not have been able to do this without them.

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Thank you to all of my Ugandan partners including those at Brick by Brick and the participants in the study. David Mutesaasira and Max Ssenyonga along with the other members of Brick by Brick including Prossy

Nakayiba and Suzan Kyambadde welcomed me and have showed me the true value of community through selflessness and working for the purpose of doing. To the Executive Director of Brick by Brick Marc Sklar, you are one of the hardest working humans whom I have ever met and your efforts have allowed me to strive in this program and for the people of Uganda to live better lives. Thank you to all other Brick by Brick partners foreign to Uganda including Anjana Krishnan, who is now interning at Brick by Brick and has helped me with the follow-up procedures after my departure. Thank you to the greater Masaka area community and the United States Peace Corps, whose staff and volunteers including Kelly Drummond and Mackenzie Leonard have helped me through this process. To the participating communities, thank you for welcoming me into your home. You have created a welcoming community that has taught me to be a better individual. Thank you to my friends for supporting me throughout this process. Thank you to my dog, Simba, for loving me unconditionally throughout this process and staying by my side.

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ABSTRACT

Reliable access to safe drinking water is one necessity for humans to live without concern for major health risks. The overall goal of this research is to improve the public health, through improved drinking water, for communities in the Rakai District in Uganda, directly, and other communities in the world, indirectly, via dissemination of knowledge. This study specifically assessed the knowledge of drinking water quality in regards to public health, their sanitation measures, and water treatment methods for users of Brick by Brick rainwater harvesting tanks in the Rakai District (N = 28) by using a knowledge, attitudes, and practice survey and a sanitary inspection; tested the water quality of the Brick by Brick rainwater harvesting tanks (N = 33) in the Rakai District for physical, chemical, and microbial parameters; and piloted a sustainable treatment technology called the *chulli* system that uses excess heat from a cookstove to treat water. Twenty of the participants identified contaminated water as a cause of diarrheal disease (N = 28). Participants perceived boiling (1), chlorine (2), and filtering (3) as the best three methods of treating water. The average score for the sanitary inspection was 2.27±2.31, which falls between the low and medium expected risk score categories. Fourteen of the thirty-three samples showed detectable levels of colony forming units for coliforms, and

two of the thirty-three samples showed detectable levels of colony forming units for *E. coli*. A demonstration *chulli* system was constructed for St. Andrew's Primary School in Rakai District and operated successfully. The research supports that the *chulli* system along with proper sanitation measures identified in the sanitary inspections can be a sustainable option for users of Brick by Brick rainwater harvesting tanks in the Rakai District.

CHAPTER 1: INTRODUCTION

Safe water is one of humans' most precious resources and is essential for survival. A lack of sustainable access to safe water can be the cause of many health related issues including diarrheal disease and nervous system damage (WHO, 2011; Jain, 2012; Fry et al., 2013; Prüss-Ustün et al., 2014). The overall goal of this research is to improve the public health, through improved[1] drinking water, for communities in the Rakai District in Uganda, directly, and other communities in the world, indirectly, via dissemination of knowledge. This project seeks to assess the need to improve management practices of rainwater as a source of water for drinking purposes, to determine the risk level of this drinking water quality, and lastly to determine the feasibility of a sustainable (low-cost, culturally appropriate, safe for the environment, and effective) treatment technology for the target population.

[1] Improved water sources have been defined by WHO/UNICEF (JMP, n.d.) as tap water in the dwelling yard or plot, public standposts, boreholes/tubewells, protected wells and springs, rainwater, packaged water, including bottled water and sachet water, and delivered water,

1.1. Problem Statement

Lack of access to improved drinking water sources is a global health issue that affects approximately 663 million people (WHO/UNICEF, 2015a) (Figure 1). Disproportionately, sub-Saharan Africa contributes to approximately half of this number (UN, 2015). Furthermore, in Uganda, the location of this study, 24% of the rural population does not have access to an improved water source (WHO/UNICEF, 2015b) (Figure 2). Rainwater harvesting is a common solution to improve access to water in stressed areas including many developing countries; however, the perception of rainwater quality as safe for potable purposes conflicts with the existing limited research revealing that harvested rainwater quality is inconsistent and oftentimes poses a health risk on the user community (Gwenzi et al., 2015; Prouty et al., 2016). Understanding the risk and providing an appropriate treatment technology are important because unsafe drinking water quality is directly related to health issues including premature fatalities caused primarily by microbial contamination prevalent in developing countries (WHO, 2011; Prüss-Ustün et al., 2014).

Although developing countries are commonly highlighted for their populations having low coverage for access to safe water, developed countries including the United States continue to have issues as well. For example, Flint, Michigan underwent a water crisis recently due to lead contamination of the water caused by a switch to a more corrosive water that was compounded by long water residence times, old age of water distribution piping, and poorest average neighborhood housing condition that resulted in harmful blood lead levels measured in its inhabitants before the intervention took place (Sadler et al., 2015). Furthermore, in Florida, a fertilizer company, Mosaic, contaminated an aquifer that supplies drinking water with wastewater via a sinkhole (The Associated, P, 2016). Although humans have introduced many technological breakthroughs (rainwater harvesting, desalination, etc.) to improve access to sufficient water resources, continuing to improve the sustainability of our management techniques will help guarantee access to this precious resource.

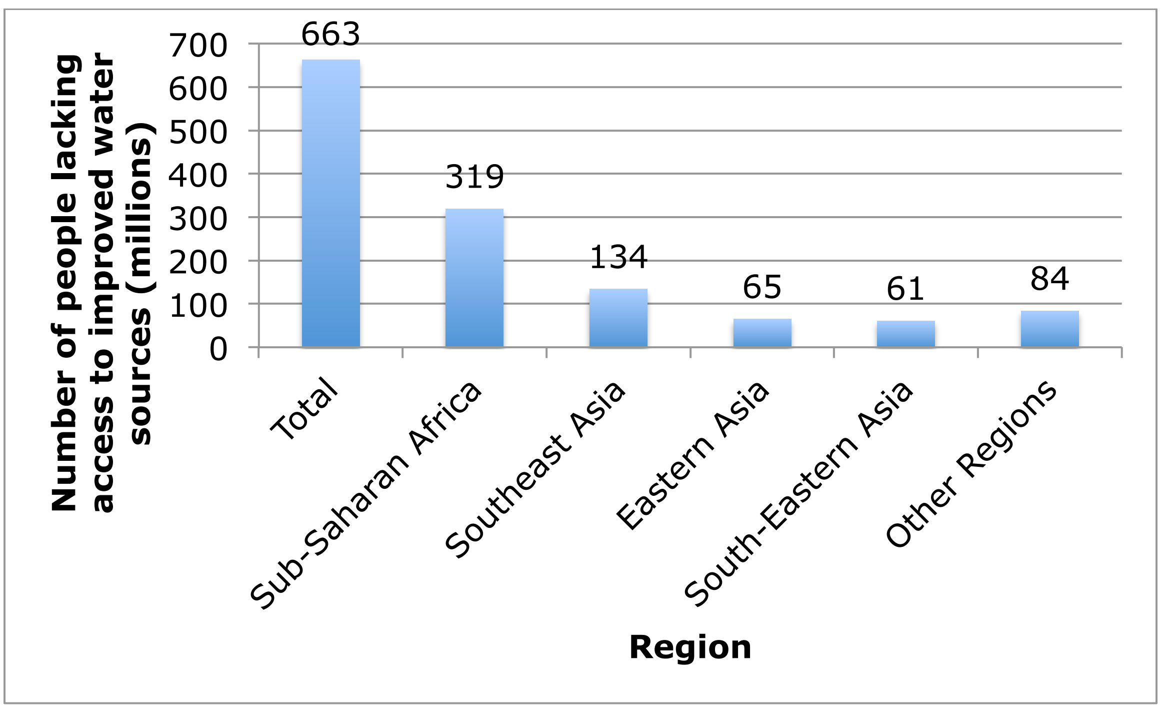

Figure 1: Global and regional populations' lack of access to improved drinking water sources (from data provided in WHO/UNICEF, 2015a).

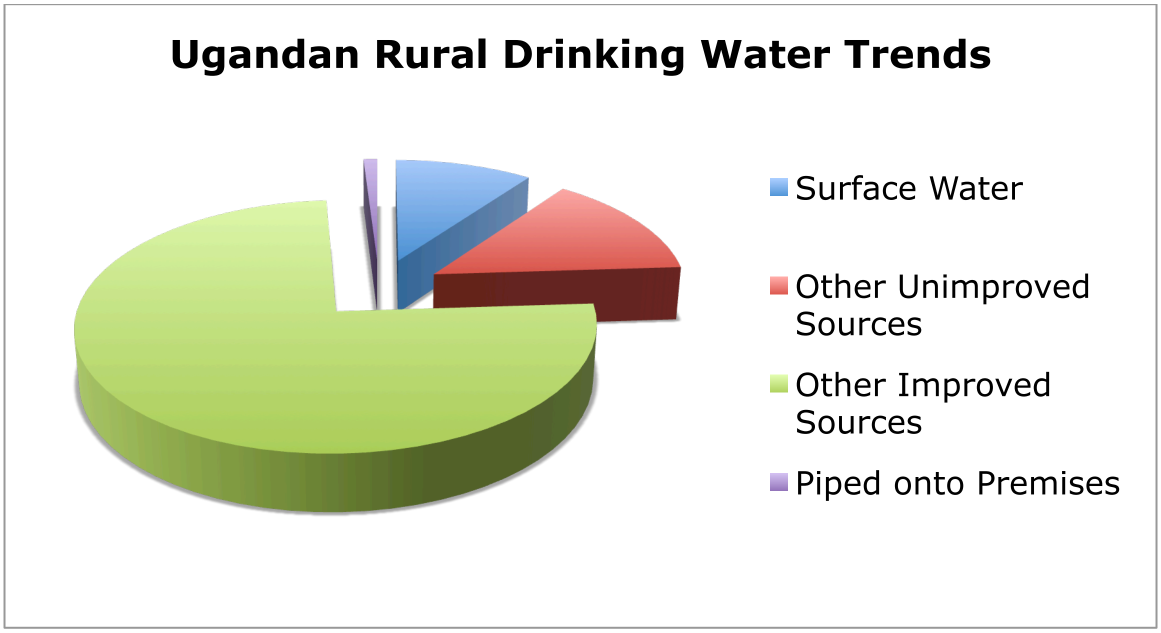

Figure 2: Ugandan rural drinking water trends (from data provided in WHO/UNICEF 2015b).

1.2. Focus Area

Communities manage their water resources differently than others due to associated environmental factors such as climate, geography, socioeconomic status, and education; however, populations can improve their management techniques through learning about experience of others. This research study is performed in the Rakai District of Uganda. Uganda is a landlocked country located in East Africa (Figure 3a), and Rakai District is located on the southern end of the country's Central Region (Figure 3b). Approximately 49% of the Rakai District population has access to safe water (Ministry of Water and Environment, 2010). In a response to this issue, a nongovernmental organization called Brick by Brick (www.brickbybrick.org) developed a social enterprise, Brick by Brick Construction, an enterprise founded by University of South Florida Master's International student, Jonathan Blanchard (Blanchard, 2012). Brick by Brick's main project is the construction of interlocking stabilized soil block (ISSB) rainwater harvesting storage tanks (Figure 4) ranging in capacity from 10,000 to 30,000 L. This provides an affordable option over other water storage tanks available in the area (Thayil-Blanchard, 2015).

Figure 3: Maps of (a) Uganda in the context of Africa (adapted from Central Intelligence Agency, 2017); (b) Rakai District in the context of other Ugandan districts (reprinted from Uganda Travel Guide, n.d.)

b)

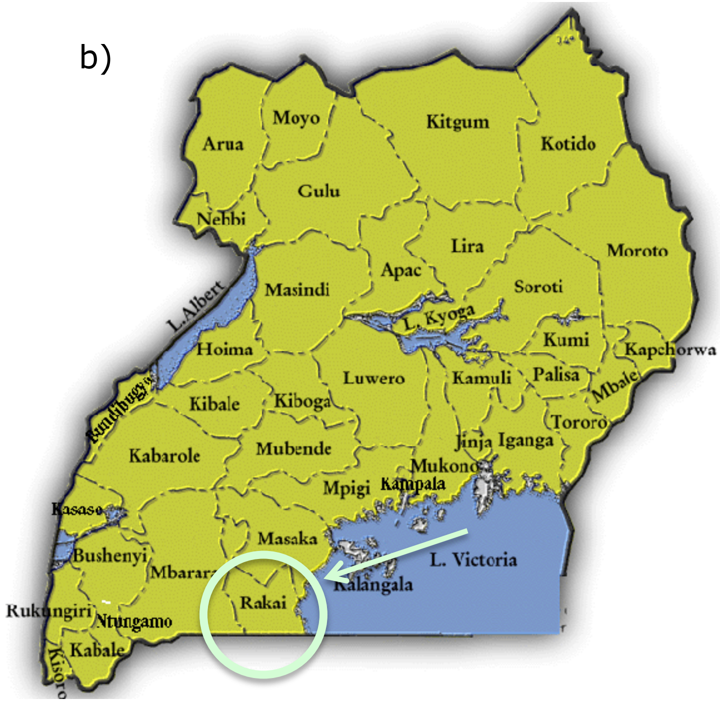

Figure 3 (Continued)

Figure 4: 30,000 Liter Brick by Brick Rainwater Harvesting Tank constructed for Bikungu Primary Teacher's College.

1.3. Water Resources and Water Quality

Drinking water can be obtained from a number of different sources including but not limited to rainwater, groundwater, and surface water that includes natural reservoirs. In order to monitor the use and safety of different water sources, the Joint Monitoring Program (WHO/UNICEF, 2015a) developed classifications for improved water sources as shown in Table 1. Although water may be obtained from an improved drinking water source, it still may not adhere to its local government's water quality standards and can pose a health risk. The sustainable development goals now include two new classifications, basic and safely managed, of water sources to address the limitations of improved water sources (WHO/UNICEF, 2017). A comparison of the classifications from both years can be found in Table 1. Although a water source may be contaminated, it can be treated to make it safe for drinking. Three of the most common stages of treatment are sedimentation, filtration, and disinfection (Mihelcic et al., 2009). Each treatment method has its advantages and disadvantages and a different effectiveness. Finding the appropriate treatment method(s) can help communities improve their health and wellbeing.

Table 1: Classifications and definitions for different water sources from 2015 (WHO/UNICEF, 2015a) and 2017 (WHO/UNICEF, 2017)

Year			
2015		2017	
Classification	Definition	Classification	Definition
Improved	Piped water on premises (tap water in the dwelling, yard, or plot or public standposts) and non-piped supplies (boreholes/tubewells, protected wells and springs, rainwater, packaged water, including bottled water and sachet water, delivered water, including tanker trucks and small carts)	Safely Managed	Improved water source located on premises, available when needed and free from faecal and priority chemical contamination
		Basic	Improved source provided collection time is not more than 30 minutes for a round trip, including queuing
		Limited	Improved source for which collection time exceeds 30 minutes for a round tip, including queuing
Unimproved	Non-piped supplies (unprotected wells and springs) and surface water (river, dam, lake, pond, stream, canal, irrigation channels)	Unimproved	Non-piped supplies (unprotected wells and springs)
		Surface Water	Directly from a river, dam, lake, pond, stream, canal, or irrigation canal

1.4. Comparison to Other Research Studies

This research study differs from others in many ways including its partnering organization, the location, and the intervention. Brick by Brick Construction has been constructing rainwater tanks for its clients since 2011. This is the first time that contents of these tanks have been evaluated for the water quality as recommended by Blanchard (2012). Though previous studies suggest that consuming rainwater does not pose a large risk for contracting gastrointestinal illness (Dean et al., 2012), other research has shown that factors such as tank material can negatively impact stored water (e.g., Schafer, 2010; Schafer and Mihelcic, 2012). In addition, this study has been performed in the Rakai District in Uganda, which has very limited research available on rainwater quality. Lastly, the technological treatment system studied here (i.e., the "*chulli* system"[2]) is not yet available globally and has seen very little application in Uganda. In addition, as discussed later of this thesis, this treatment system has the opportunity to be a more sustainable approach to water treatment in this region. This study thus has the potential to assist some of the Rakai District's population improve its approach to water treatment directly and help others globally learn from the results.

1.5. Hypotheses and Objectives

This thesis has the following hypotheses and associated objectives:

Hypothesis #1: Users of Brick by Brick rainwater harvesting tanks in the Rakai District can improve their knowledge of drinking water quality in

[2] A *chulli* system uses small clay stoves, called *chullis* in Bangladesh, to disinfect water using excess heat from a stove through an inserted coiled pipe. This system is explained more in detail in the following chapters.

regards to public health, their sanitation measures, and water treatment methods.

Objective 1.a: Assess the users' knowledge of drinking water quality in regards to health especially in the case microbial contamination

Objective 1.b: Perform a sanitary inspection to assess the expected risk associated with consuming the harvested rainwater

Objective 1.c: Identify the largest areas for improvement for their drinking water management methods in the study location

Objective 1.d: Identify water treatment methods in the study location and respective areas for environmental, economic, and effective improvements

Hypothesis #2: The water quality of the Brick by Brick rainwater harvesting tanks in the Rakai District will not meet the Ugandan drinking microbial water standards.

Objective 2.a: Test the Brick by Brick rainwater harvesting tank for microbial contamination

Objective 2.b: Compare the water quality test with the Ugandan national standards

Objective 2.c: Assess the level of health risk of drinking the harvested rainwater

Hypothesis #3: The suggested treatment technology will be well-received by the community and effectively treat the rainwater.

Objective 3.a: Design the treatment technology using local materials

Objective 3.b: Introduce the treatment technology to selected participants

Objective 3.c: Test the treated water

Objective 3.d: Compare the results of the treated water quality test to the raw water quality tests

Objective 3.e: Survey the users of the treatment technology to assess the level of approval of the technology

Objective 3.f: Identify any barriers, which would cause resistance to using the treatment technology

CHAPTER 2: LITERATURE REVIEW

2.1. Drinking Water Quality and Public Health

All humans require an adequate supply of clean water in order to survive, and a lack of this resource is known to significantly decrease the quality of life (WHO, 2011). The level of access to clean water varies over different populations; however, four criteria can determine whether users have or do not have access to this resource: 1) a sufficient quantity, 2) an acceptable quality, 3) local availability, and 4) affordable price (Jain et al., 2011).

Although many people have access to a sufficient supply of water, many still do not. The WHO/UNICEF Joint Monitoring Program reports that approximately 663 million people do not use an improved drinking water source (WHO/UNICEF, 2015c). Disproportionately, sub-Saharan Africa contributes to approximately half the population that lacks access to improved drinking water sources (WHO/UNICEF, 2015c), and elderly, young and those in unsanitary conditions endure the severest health impacts including death from the scarcity of this resource (WHO, 2011). Although global reports provide estimates on those now being serviced by improved water sources, the term improved can be deceiving or inaccurate. For example, monitoring and evaluation have revealed only 34% of reported improved water sources adhered to the originally developed standards in some instances (Howard et al., 2012). Consequently, the actual number of people being served by improved water sources most likely falls below than what is formally reported.

Unsafe drinking water can pose a health risk to the consumer if its level of contamination is significant enough. However, recognizing harmful drinking water can be difficult because of unobvious indicators, a lack of knowledge of health risks, and a great variance in quality over time and distance (Howard, 2002). Unclean water can have different types and levels of contamination, and most contamination occurs due to anthropological activities (Jain, 2012). Typical water quality parameters important for public health include presence of microbiological indicators and pathogens, turbidity and suspended solids, and inorganic and organic pollutants. Although each of these parameters can have associated health risks, many agree that microbial contamination poses the greatest health risk to humans in developing world settings in regards to drinking water contaminants (Howard, 2002; Jain et al., 2011; WHO, 2011; Jain, 2012; Prüss-Ustün et al., 2014). Exposure to pathogens may be associated with the stomach flu, diarrhea, and vomiting (Pathak et al., 2006). Independently, turbidity itself is not a health risk; however, turbidity is associated with the concentration of suspended solids (SS) to which harmful microorganisms or other pollutants can be attached (Howard, 2002). Turbid and odorous water can also be aesthetically unpleasing resulting in rejection by the user (WHO, 2011). Lastly, heavy metal contamination may cause acute or chronic health issues; this contamination can result from leaching from premise-plumbing materials like galvanized iron and lead pipes, copper pipes, steel pipes, brass fittings and taps (Akers et al., 2015; Masters et al., 2016; Ab Razak et al., 2016).

Many different types of water sources can be contaminated, and drinking water quality can be sacrificed for many different reasons. Although improved drinking water sources theoretically provide safe drinking, limited monitoring, inadequate treatment, poor maintenance, and short-term contamination can result in these improved sources failing to provide users with an adequate supply (Howard et al., 2012). More information and research can help further the understanding of the health risks of possibly contaminated water sources like harvested rainwater (Kwaadsteniet et al., 2013). Still, unimproved sources such as shallow wells and surface water have been shown to have higher microbial contamination and reduced risk of illness (Dean et al., 2012; Abraham et al., 2015). As noted, improved sources can be contaminated after distribution or construction, but supplying agencies hold responsibility for these technologies supplying safe water (WHO, 2011). Given that water can be contaminated and pose a health risk, disinfection is highly recommended in order to ensure safe drinking water (WHO, 2011).

2.2. Rainwater and Storage Tank Quality

Traditionally harvested rainwater has been considered safe; however, recent research has found that harvested rainwater can very in quality over different seasons (Hamilton et al., 2017), become contaminated from a number of different contamination routes (Figure 5), and pose a significant health risk (Gwenzi et al., 2015). For this reason and due to limited research on harvested rainwater quality in developing nations, many suggest that rainwater quality and the potential health impact should be investigated further (Blanchard, 2013; Kwaadsteniet et al., 2013). A previous study investigating the microbial and chemical contamination of different water sources in Ugandan households in Wakiso District showed that rainwater quality was commonly perceived as safe; however, water quality tests revealed that harvested rainwater had the highest concentration of microbial indicators, 3 CFU/ 100 mL for *E. coli*, of the evaluated sources including boreholes, protected springs, rainwater, and piped supply, <1 CFU/ 100 mL, with the exception of surface water (Prouty et al., 2016). Additionally, a study in Cochabamba, Bolivia, showed that six types of household storage tanks receiving water from a distribution system from two water sources including two wells and treated water from the River Khora showed that

28.6% to 71.4% of the samples from each tested container type failed to meet the national standards for *E. coli* (Schafer, 2010; Schafer and Mihelcic, 2012).

Before contacting a surface, rainwater is usually considered safe being the only possible source of contamination is airborne. However, further and more signification contamination occurs between collection and distribution processes (Gwenzi et al., 2015). Researchers are still investigating the likely sources of rainwater contamination, and they have been making progress in identifying these routes. For example, a study in South Africa that examined the efficiency of pasteurizing rainwater contaminated with *E. coli, Yersinia spp., Legionella spp., and Pseudomonas spp.* identified that a dirt road frequented by both motorcycles and cattle could be a possible source of contamination (Dobrowsky et al., 2015). In addition, commonly accepted prevention measures against contamination have shown to be less effective than originally hypothesized. For example, a very commonly used component of rainwater harvesting systems used to prevent contamination, the first flush system, has been shown to not be consistently effective in preventing microbial contamination. Two possible reasons for the ineffectiveness of some first flush systems can be the insufficient magnitude of the rainfall and the contamination of the rainwater itself before reaching the catchment surface (Gwenzi et al., 2015).

Harvested rainwater can have many routes of contamination as shown in Figure 5; furthermore, quantifying the level of contamination and understanding the specific contaminants determine the degree of risk. Ten noticeable routes of contamination of rainwater are shown in Figure 5:

[1] Sign of contamination on the roof

[2] Dirty or blocked gutter system

[3] Filter box or first flush issues

[4] Uncovered point of entry

[5] Cracked or damaged tank

[6] Leaking or broken tap

[7] Missing, broken, or dirty concrete floor under tap

[8] Inadequately drained collection area

[9] Source of contamination around the tank or collection area

[10] An unsupervised bucket able to be contaminated

In order to provide guidance for determining the acceptability of drinking water quality, both international and national water quality standards have been developed in regards to maximum allowable levels of microbial and chemical contamination. Local standards have been developed versus international standards based on a risk-benefit approach given a location's available resources and health priorities (WHO, 2011). A study (Prouty et al., 2016) investigating rainwater quality from storage containers constructed from corrugated metal sheets ranging in capacity from 3000-

5000 L in households in Wakiso, Uganda, revealed high (relative to other local sources such as boreholes, protected springs, and tap water) levels of TDS (76 mg/L), turbidity (3.4 NTU), and *E. coli* (3 CFU/100 mL) failing to meet both international and national microbial contamination standards. Noteworthy, that study mentioned that the small water sample size was a limitation, and a larger sample size could have produced more generalizable results (Prouty et al., 2016). That study associated the lack of first flush systems with the tested rainwater harvesting systems as possible source for level of contamination (3 CFU/ 100 mL). Another study that reviewed rainwater quality in several developing and developed nations in North America, Europe, Asia, Africa, and Australia reported that a number of pathogens, including *E. coli*, *Aeromonas spp*., *Campylobacter spp.*, *Salmonella spp.*, and *Giardia spp*., and chemical contaminants have been detected in rainwater harvesting systems (Kwaadsteniet et al., 2013). Table 2 provides a summary of selected research that identified microbiological contaminants and indicators in harvested rainwater. As shown in Table 2, *Aeromonas spp.*, *Campylobacter spp.*, *E. coli*, *Heterotrophs*, *Legionella spp.*, *Pseudomonas spp.*, *Salmonella typhimurium*, *Cryptosporidium spp.,* and *Giardia spp.* are all possible water constituents that are considered either bacterial or protozoan and have all been detected or associated with rainwater. Consequently, previous research shows that informal urban and rural populations need effective and cautionary rainwater harvesting methods used for potable purposes to prevent health issues from this improved water source (Dobrowsky et al., 2015).

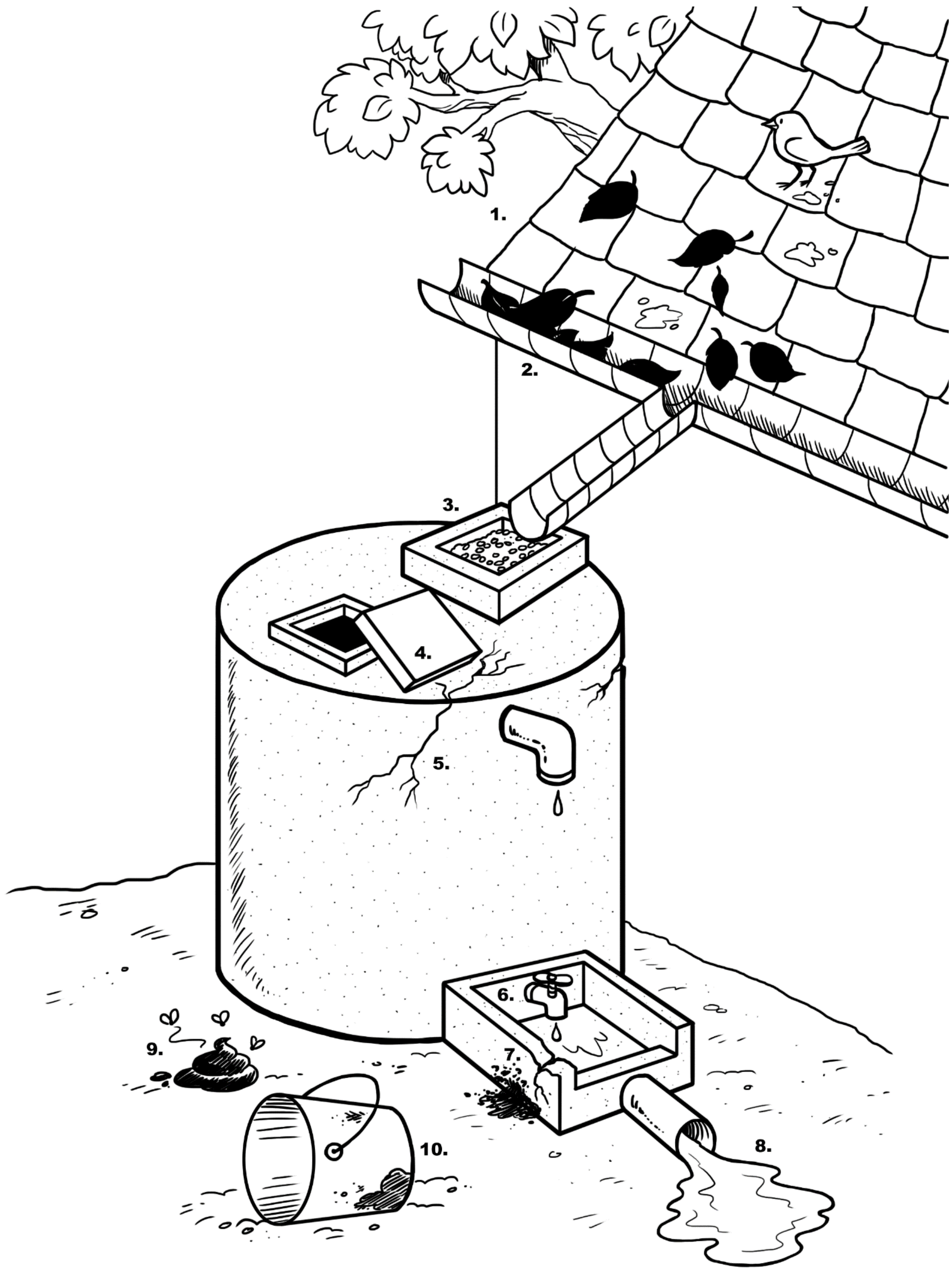

Figure 5: The possible routes of contamination for rainwater (reprinted with permission from the Center for Affordable Water and Sanitation Technology under the Creative Commons Attribution Works 3.0 Unported License (2013)).

Table 2: Summary of studied microbiological contaminants in rainwater and relevant study details

Type of Contaminant	Specific Tested Contaminant	Patho-genic	Location	Number of Samples Taken	% of Positive Samples	Range of Concentrations	Unit	Collection container volume	Factors associated with the presence of contaminant[+]	Reference
Bacterial	*Aeromonas spp.*	Yes	Auckland, New Zealand	125	16 (20)	n.d.	N/A	250 mL	tiled roof catchments	Simmons et al., 2001; Kaushik et al., 2012
			National University of Singapore, Singapore	50	2 (1)	0-33.2	gene copies / 100 mL	100 mL		
	Campylo-bacter jejuni	Yes	Auckland, New Zealand	115	0	n.d.	N/A	250 mL	wild animal feces, unclean roofs, unclean gutters	Merritt et al., 1999; Simmons et al., 2001
			Queensland, Australia	n.d.	n.d.	n.d.	n.d.	n.d.		
	E. coli	Some Strains	Gangneung, South Korea.	n.d.	72	0-60	CFU/ 100 mL	2 L	atmospheric pollution from biomass burning, lack of first flush, poor hygiene, maintenance, tank surfaces, surface runoff, rooftop surfaces, highway traffic emissions	Sazalaki et al., 2007; Vialle et al., 2011; Kaushik et al., 2012 ; Dobrowsky et al., 2014; Kaushik et al., 2014; Prouty el. al. 2016
			Kefalonia Island, Greece	156	40.9	0-250	CFU/ 100 mL	n.d.		
			Kleinmond, South Africa	80	62 (50)	0-250	CFU/ 100 mL	2 L		
			National University of Singapore, Singapore	50	42 (21)	0-14000	gene copies / 100 mL	100 mL		
			rural village, south-western France	n.d.	79	<10-5500	CFU/ 100 mL	n.d.		

Table 2 (Continued)

Bacterial	*E. coli*	Some Strains	Upper Pierce Reservoir, Singapore	33	n.d.	0-75	CFU/ 100 mL	1 L	atmospheric pollution from biomass burning, lack of first flush, poor hygiene, maintenance, tank surfaces, surface runoff, rooftop surfaces, highway traffic emissions	Sazalaki et al., 2007; Vialle et al., 2011; Kaushik et al., 2012 ; Dobrowsky et al., 2014; Kaushik et al., 2014; Prouty el. al. 2016
			Wakiso District, Uganda	2	n.d.	3	CFU/ 100 mL	250 mL		
	Heterotrophs	Some micro-organisms	Auckland, New Zealand	125	100 (125)	1-130,000	CFU/ 250 mL	250 mL	galvanized iron roof, galvanized iron storage tank	Simmons et al., 2001; Kaushik et al. 2014
			Upper Pierce Reservoir, Singapore	33	100	10-139	CFU/ 100 mL	1 L		
	Legionella spp.	Some species	Auckland, New Zealand	23	0	n.d.	N/A	250 mL	aerosol particles, mammalian cells	Simmons et al., 2001; Reyneke et al. 2016
			Stellenbosch University, South Africa	8	100	470000-60000000	gene copies/ mL	3 L		
	Pseudomonas aeruginosa	Yes	Kefalonia Island, Greece	156	0	0-0	CFU/ 100 mL	n.d.	atmospheric microbiological pollution from biomass burning, mountain catchments, rainy season, dust, leaves, bird droppings	Sazalaki et al., 2007; Kaushik et al., 2012; Nawaz et al., 2014
			Seoul National University, South Korea	n. d.	n. d.	30-1800	CFU/ 100 mL	0.5-1 L		

Table 2 (Continued)

Bacterial	*Pseudomonas aeruginosa*	Yes	National University of Singapore, Singapore	50	32 (16)	0-1200	gene copies / 100 mL	100 mL	atmospheric microbiological pollution from biomass burning, mountain catchments, rainy season, dust, leaves, bird droppings	Sazalaki et al., 2007; Kaushik et al., 2012; Nawaz et al., 2014
	Salmonella typhimurium	Yes	Auckland, New Zealand	115	0.9 (1)	n.d.	N/A	250 mL	Lack of disinfection, dirt, leaves, bird feces, and animal droppings	Simmons et al., 2001; Koplan et al., 1978; Franklin et al., 2009
			rural Victoria, Australia	4	2 (50)	n.d.	n.d.	15 L		
			Trinidad, West Indies	n.d.	n.d.	n.d.	n.d.	N/A		
Protozoan	*Crypto-sporidium spp.*	Yes	Auckland, New Zealand	50	4 (2)	n.d.	N/A	500 mL	contaminated tank, rodents, unclean catchment surface, animal feces	Simmons et al., 2001; Crabtree et al., 2009
			US Virgin Islands*	52	n.d.	<1-70	CFU/ 100 mL	350-450 mL		
	Giardia spp.	Yes	Auckland, New Zealand	50	0	n.d.	N/A	500 mL	contaminated tank, rodents, unclean catchment surface, animal feces	Simmons et al., 2001; Crabtree et al., 2009; Fonseca et al., 2014
			Jequitinhonha Valley, Brazil	n.d.	n.d.	n.d.	n.d.	N/A		
			US Virgin Islands*	52	n.d.	<1-70	CFU/ 100 mL	350-450 mL		

* This study did not explicitly state the difference between Cryptosporidium and Giardia results; therefore, the data were combined.
\+ Other factors may be associated with specific rainwater contaminants; however, this table includes the ones specifically mentioned in the cited studies.

2.3. Associated Perceptions and Practices

Investigating knowledge, attitudes, and practices of individuals and communities can assist researchers understand the reasons behind consumption of unsafe drinking water and accordingly, develop successful interventions (Ab Razak et al., 2016). Previous analyses have improved our understand of the common reasons of operation associated with health risks and further develop focal point for new studies.

As stated previously, the greatest concern related to unsafe drinking water is microbial contamination (Howard, 2002; Jain et al., 2011; WHO, 2011; Jain, 2012; Prüss-Ustün et al., 2014), yet many do not prioritize preventing this. A study in Iran found that turbidity and corrosiveness were the two causes for health and acceptability issues (Abtahi et al., 2015). Another study conducted in western Kenya showed that communities perceived water to be safe for consumption given favorable physical parameters including the lack of suspended solids that would cause odor and color (Kioko and Obiri, 2012). In regards to causes of illnesses, a study in rural southern India revealed that community members did not believe that consumption of contaminated drinking water caused diarrheal diseases (Francis et al., 2015). Concerning perceptions of safety, survey responses in central Uganda indicated rainwater could be consumed safely if it did not remain stagnant (Prouty et al., 2016). Each example shows that these easily recognizable factors cause concern about their drinking water.

However, the knowledge about the significant risk of microbial pathogenic contamination of water is limited.

Although many cases demonstrate that faulty perceptions result in the consumption of unsafe water, communities sometimes continue risky practices even with appropriate knowledge. For example, the study in western Kenya revealed that survey respondents were both knowledgeable of good hygienic practices and treatment, collection, and storage methods, yet the communities did not practice them (Kioko and Obiri, 2012). In addition, the study mentioned previously from India (Francis et al., 2015) concluded that the simplicity of access from the sources, and the economic requirements along with the ability to recognize health benefits, directly related to the successful impact of interventions and sustained practices. Therefore, communities' existing perceptions, practices, and priorities help explain some reasoning behind consumption of unsafe drinking water and guide successful intervention plans.

2.4. Testing Water Quality

Water quality tests can determine the potential threat of using a certain water source. Moreover, test results are necessary for developing public health measures and interventions to minimize the risk and improve the health of the users (Gwenzi et al., 2015). Although measuring water quality informs methods for subsequent actions, barriers associated with testing water quality exist. For example, microbial contamination of water poses a possible health risk on communities; however, microbial quality oftentimes remains unknown due to the cost, difficult, time requirement, and skilled expertise needed for conducting the tests (Gunda et al., 2016). As a result, rural settings with limited resources and non-piped water sources most in need of assessing due to the likelihood of contamination receive the least monitoring. This information underscores the need for more water quality testing at a greater convenience than currently commercially available for low-resource areas and decentralized water sources.

In addition to determining the water risk level, water quality tests also serve other purposes. For example, water test results can help determine specific routes exposure by a direct comparison. So, water quality tests along with recording potential risk factors such as the seasonality or sanitary conditions can help identify trends in quality and the strongest associated risk factors or routes of contamination. Additionally, test results can also determine whether samples comply with national or international standards (Howard et al., 2012). Moreover, water quality tests can be used to show the effectiveness of a treatment technology by showing the level of reduction of contaminants by comparing the raw water to the treated water (CAWST, 2013). Conclusively, water quality tests can serve many purposes and provide valuable information towards improving public health.

Before performing a water quality test and interpreting results, the analyst must determine the most effective and appropriate methods. The analyst should consider the location and communal amenities in regards to the water source. Many countries have national drinking water quality standards, which should be used as guidelines if they exist (Blanchard, 2012). Also, the tests should consider the population's available resources such as community member technical expertise and health priorities (WHO, 2011). Outbreaks of specific diseases often result from contaminated drinking water sources; however, testing for specific microbial pathogens can be very difficult and costly. Therefore, using indicator bacteria such as total coliforms and *E. coli* present the likelihood of fecal contamination with other microbial pathogens (Howard, 2002; CAWST 2013). In addition to testing for microbial water quality, testing for turbidity tests can also determine the likelihood of acceptance and possible health risk due to the possibility of bacteria being attached to suspended solids that are related to turbidity (Howard, 2002).

Analysts should also determine ways of performing the test. For example, flaming a tap, applying a flame directly to a tap for sterilization of the outlet, is sometimes recommended before testing water. An advantage of flaming would be that the source of the water is measured. The advantage of not flaming is that the consumed water is tested (Howard, 2002). Lastly, complementing sanitary inspections with water quality tests can help determine factors influencing contamination and help guide management improvements (Howard, 2002). Before performing a water quality analysis, many factors including the specific location and purpose of the test should be determined.

Different microbial water quality tests exist, and most have their advantages and disadvantages. Three common methods of testing for indicators of fecal contamination are presence/absence (PA), most probable (MPN), and membrane filtration tests. A presence/absence test does not enumerate the testing parameter but determines whether or not the contaminant is present (Adegbite, 2015). An MPN estimates the quantity of a contaminant present. A membrane filtration test such EPA Method 1603 provides the most accurate quantitative results of the contamination compared to the others. Given these three types of tests, the accuracy, costs, and required technical capacity all vary directly. In order words, an increased accuracy of the test implies higher costs and a great technical knowledge (CAWST, 2013).

A study in the United Kingdom compared Delagua, Colilert (P/A), Colilert (MPN) and Petrifilm methods considering variables including ease of use, accuracy, cost, and portability under emergency situations. That study suggested that the Colilert (MPN) is the most appropriate test given the selection criteria (Adegbite, 2015). In addition to the types of microbial tests, tests typically also require samples to be incubated. Many methods of incubation exist including using an electronic incubator, a thermos, or human body belt. The human body belt has been investigated further due to its potential to provide accurate results at lower costs and increased convenience. The previous study from the United Kingdom also showed that the human body incubation provided accurate water quality test results (Adegbite, 2015). Adding to these traditional tests, researchers are continuing to develop innovative, accurate, and cost-effective methods. For example, a compartment bag test (CBT) uses a statistical analysis based on the number of positive compartmentalized volumes of a water sample to enumerate levels of *E. coli* (Weiss et al., 2016). A study in Canada developed a cheap and fast test for *E. coli*; however, the water sample size did not comply with US EPA standards (Gunda et al., 2016).

Given that many low-resource settings need water quality testing, minimizing the cost is a paramount concern. Due to the lack of testing sites especially in rural settings and the need for trained personnel, transportation and labor can contribute to 75% of marginal costs for water quality tests (Crocker et al., 2014). This highlights the need and potential benefits of creating more testing locations and easier testing methods. Another factor that often increases testing costs are the need for an expensive incubator. A human body belt that can be used as an incubator is a cheap alternative, provides accurate results, and does not require electricity; one vest that can be used as an incubator costs £39.80 (Adegbite, 2015). New testing methods have been able to detect *E. coli* within one hour compared to other that usually take twenty-four hours at an estimated price range of CAD 2-3 for each test. As new technology become available, microbial water tests are becoming easier and less expensive.

2.5. Managing Water Quality – Contamination Prevention and Treatment Technologies

Many different factors affect whether or not a community manages its water effectively and safely for consumption. The three pillars of sustainability (social, economic, and environment) should be considered when evaluating community management and suggesting interventions in order to increase the likelihood of success (Kates et al., 2005). Especially in developing communities, which may already have the preconceived perceptions and established practices, interventions must be culturally acceptable, inexpensive, simple, and easy to use (Kwaadsteniet et al., 2013). In addition, the communities should be involved as much as possible during all stages of the intervention to help ensure sustainability (Francis et al., 2015). For water management interventions specifically, many agree that three paramount points of intervention including education, treatment, and recontamination prevention (Schafer, 2010; Jain, 2012; Gwenzi et al., 2015). Due to the management structure, educational setting, and general openness to innovation, schools are considered to be appropriate institutions for water management interventions (Meierhofer and Wegelin, 2002) .

Water treatment can effectively prevent exposure to harmful contaminants and reduce pathogen concentrations. Many different treatment types and technologies exist, and the quality of the raw water should be one factor determining the selected method (Kioko and Obiri, 2012). In other words, different technologies have their advantages and disadvantages, and the specific factors including water quality and the environment can guide, which treatment method or combination of treatment methods is most appropriate. Three of the most general types of treatment include sedimentation, filtration, and disinfection (Mihelcic et al., 2009; CAWST, 2013). Each of these general types of treatment methods includes more specific types of treatment technologies that vary in their treatment levels and effectiveness. For rainwater specifically, different studies recommend different treatment processes. For example, on study in Uganda recommends a combination of settling, filtration, boiling, and sodium hypochlorite (Prouty et al., 2016). Another comprehensive review of rainwater harvesting mentions that a first flush system is an engineering safeguard to prevent contamination (Gwenzi et al., 2015); on the contrary, another study in South Africa chose not to install first flush systems due to their previously researched ineffectiveness (Abraham et al., 2015).

One general type of water treatment method is filtration, which involved separating contaminates as the water passes through smaller pores. Many types of filters exist, and sand filters are very commonly used. Slow sand filters are common in developing countries; they have a porous filter media, which is able to filter helminths and some protozoa at a flow rate of 480,000 L/day (Peter-Varbanets, 2009; Kwaadsteniet et al., 2013;). Alternatively, rapid sand filter have a filter media with larger pore sizes, which can be an effective pretreatment method to reduce turbidity at a faster flow rate but is ineffective at reducing microbial contamination (Abraham et al., 2015). A study on a sand filter composed of fine gravel and fine sand from the Red River banks, highlighting the simplicity of obtaining this essential material for the filter, significantly reduced arsenic and iron concentrations (95% and 100% respectively); however, the authors suggested disinfection of the effluent water before consumption due to increased microbial contamination. Many different types of sand filters exist, and users are developing inexpensive and innovative design in developing countries. For example, some designs use local materials including cast iron, brick shards, sand, and charcoal that have been successful at reducing both arsenic and coliforms (Ray and Jain, 2011). Another design separated layers of the sand filter with spaces in between to diminish commons issues with sand filters such as clogging, odor, and excessive spatial requirements

(Nitzsche et al., 2015). Another study found that two full-scale biosand filters reduced *E. coli* at a $\log_{10}$ removal of 1.7 (Lynn et al., 2013).

Disinfection is another type of water treatment, which involves inactivating microbial contaminants (Abtahi et al., 2015). Three common types of disinfection include chemical, heat, and UV disinfection as outlined in the Global Water Pathogen Project website at http://www.waterpathogens.org/. Chlorination is the most commonly used type of chemical disinfection shown to be the most widely used treatment method in a Western Kenyan study (Kioko and Obiri, 2012); however, chlorination can fail to disinfect some protozoan pathogens such *Cryptosporidium* and some viruses (WHO, 2011). Boiling is generally the most highly recommended treatment method (WHO, 2011), but this most oftentimes requires fuel for heating such as firewood, which could have negative environmental impacts including deforestation and high carbon footprint (Islam et al., 2006; Held et al., 2013). Pasteurization, heating at temperatures below boiling point, is also effective at removing pathogens; however, indicator bacteria such as *E. coli* can be reduced detection limits while other pathogens such as *Yersinia spp., Legionella spp.* and *Pseudomonas spp.* can still survive at the same temperatures (Kioko and Obiri, 2012). Research has been conducted showing the inactivation of microorganisms in an aqueous solution depends on water temperature and heating time period. For example, it is reported that a time period of approximately 12 seconds is required kill 99.999% of *E. coli*, rotavirus, *Salmonella typhi*, *Vibrio cholerae*, and *Shigella* sp. at a pasteurization temperature of 70 ºC. The required temperature to inactivate the microorganisms decreases exponentially with time. For example, 90% of *E. coli* organisms are inactivated at a temperature of 65 ºC for 12 seconds; the same result is achieved at 60 ºC for one minute (Ray and Jain, 2011). Another type of disinfection, called SODIS, uses a synergetic effect from both increased temperatures that leads to pasteurization and UV light to reduce microbial contamination in water (Meierhofer and Wegelin, 2002). A major advantage of disinfection as a treatment method versus sedimentation and filtration is that disinfection inactivates small contaminants like viruses and bacteria, which are usually not reduced significantly by filtration and sedimentation.

Researchers (Islam et al., 2006) developed a new and innovative treatment technology for rural households and communities that effectively treats water and is environmentally friend, cost-effective, socially acceptable, and beneficial to public; they named this technology the *chulli* water-treatment system. This system combines both filtration and pasteurization to treat water: the raw water passes through a sand filter followed by passing through a coiled pipe embedded in a stove. The water passes through the system while the user is cooking to utilize the extra heat. This system was found to be able to treat up to 90 Liters of water from different sources (ponds, rivers, lakes, and rainwater) per day, and the system completely inactivated thermotolerant coliforms with no detectable limits for over 400 field tests in Bangladesh with influent concentrations ranging from 1,750 to 560,000 cfu/100 mL. This system also has environmental benefits by eliminating the need for extra fuel that would have been used during boiling as an alternative. Additionally, the users save time because the system works during an activity that is assumed to already be happening. The study found that the system was socially acceptable partly due to the fact that the community was aware of heating water as a way of rendering it safe and reducing illnesses. Lastly, the study showed that the system is inexpensive (total cost of US$ 6) making it affordable for low-resource communities. Therefore, the *chulli* water-treatment system shown in Figure 8 and Figure 9 may be an effective way of treating water for a diverse number of developing communities (Islam et al., 2006).

CHAPTER 3: METHODS

This chapter discusses the methods used to conduct this research and achieve its objectives. Included are the preparation, sample selection, tools and instrumentation, and procedures.

3.1. Preparation

In preparation for this study, the thesis author lived in the country of the research for eighteen months working as a water/sanitation engineer, where he had the opportunity to observe local water management practices (Mihelcic et al., 2006; Mihelcic et al., 2010; Manser et al., 2015).

This experience helped him further understand the culture and the current management practices and knowledge of water quality in relation to health. During this time he observed the population's practices, and looked for trends in behaviors that could be improved.

3.2. Research Populations

The target population for this research is any person who manages and/or consumes water in the study population. Every human manages and/or consumes water; therefore, understanding perceptions and practices in relation to public health risks is applicable to all individuals in the study location. Due to the thesis author's two-year internship with Brick by Brick (Masaka, Uganda), the organization's clients and beneficiaries of their rainwater harvesting tanks are considered as the source population. Brick by Brick has constructed rainwater harvesting tanks in all regions in Uganda since its founding in 2011. The majority of Brick by Brick's work is performed in the Rakai District bordering Masaka and directly south of it (refer to Figure 3). As of July 2017, twenty-eight sites including eighteen homes, nine schools, and one health center in the Rakai District have had rainwater harvesting tanks constructed for them. Therefore, due to convenience and resource constraints (transportation time, budget, ease of communication), the sample population consisted of the adult owners of the rainwater harvesting tanks. All subjects in the available sample population were included in the study population. These research populations are summarized in Figure 6.

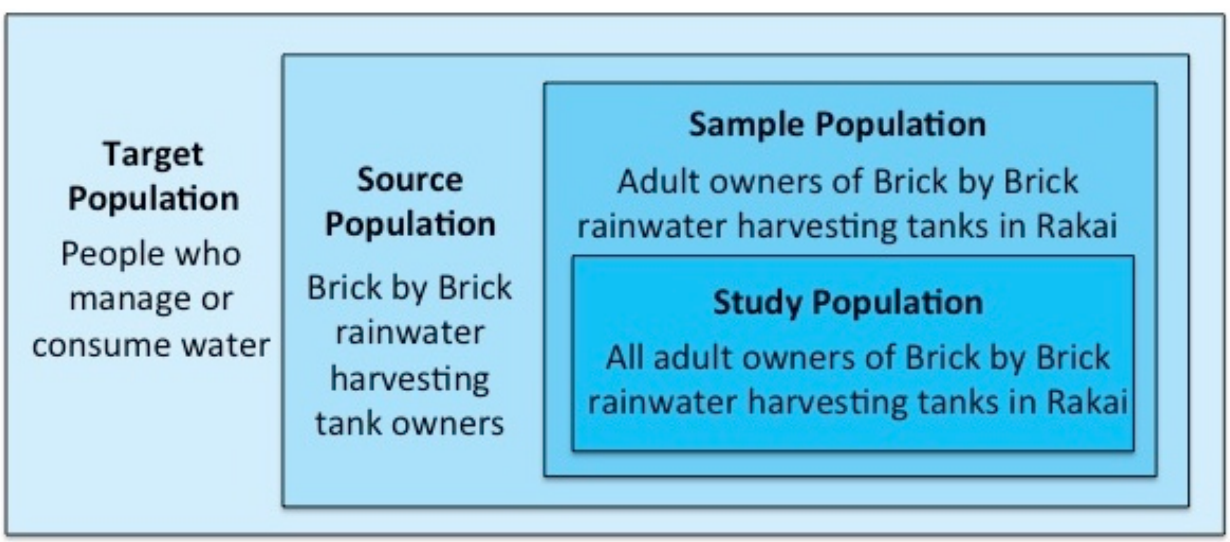

Figure 6: Definition of research populations used in this study.

3.3. Tools and Instrumentation

The following three tools and instrumentation were used to collect the thesis data: 1) a knowledge, attitudes, and practices survey, 2) a sanitary inspection, and 3) water quality tests. In addition to these tools, the principal investigator also developed a water treatment system adapted from the *chulli* water treatment system (discussed in the previous chapter).

Both the University of South Florida's Institutional Review Board and the International Health Sciences University Research Ethics Committee in Kampala, Uganda reviewed this project. The University of South Florida exempted this project from their review process for their reasoning that the activities are designed to establish the need for and creation of a water treatment system as opposed to contributing to generalizable scientific knowledge, APPENDIX A. The International Health Sciences University Research Ethics Committee located in Kampala, Uganda, approved this project, APPENDIX B. Lastly, participants were incentivized to participate in the project by receiving an entry in a raffle for the *chulli* system as a prize (one for a household and one for an institution). The applications for both review boards included an explanation of the raffle, and both approved.

International research in developing countries presents cross-cultural barriers and potential ethical dilemmas. The author spent over a year in the country before performing this research. During this time he was able to learn many of the social and cultural norms. This was useful for the design of the study and collecting accurate data.

3.3.1. Survey

A cross-sectional and qualitative survey was developed to address Objectives 1.a, 1.c, 1.d, 3.b, and 3.f. The complete survey is provided in APPENDIX C. The survey asked for participants' knowledge and attitudes about health risks, causes, and preventions associated with contaminated rainwater to address Objective 1.a. Questions about current drinking water management methods addressed Objective 1.c. Questions were included about the users' current or lack of water treatment methods were used to address objective 1.d. Introducing and asking questions in the survey about perceptions of the treatment system were used to fulfill objectives 3.b and 3.f. Lastly, some qualitative questions were included to account for possible responses that were not included in the survey. Additionally, participants were able to provide any closing remarks to help identify areas of concern and guide further research.

3.3.2. Sanitary Inspections

In addition to the survey, an adapted sanitary inspection was used to determine likely routes of contamination and estimate the risk of consumption addressing Objectives 1.b, 1.c, and 2.c. The complete sanitary inspection from CAWST (2013) is provided in APPENDIX D. The sanitary inspection for this research included ten questions specifically related to the sanitary conditions of a rainwater harvesting system. The purpose of this sanitary inspection was to help approximate the health risk of the rainwater harvesting system based on possible routes of contamination for the user without the need of water quality tests. After completing the sanitary inspection, the user received a score ranging from zero to ten with zero being the lowest health risk and ten being the highest. The results from the sanitary inspection were later compared to the results of the water quality tests in order to test the validity of the sanitary inspection tool. A high correlation supports that the sanitary inspection is an effective tool for measuring the risk of the water, and a low correlation would deem this sanitary inspection tool as inconclusive for this project. A high correlation would also suggest that the sanitary inspection tool is effective for estimating the level of risk of the rainwater harvesting system hence helping communities monitor their water practices more easily and at a low cost.

3.3.3. Water Quality Tests

Water quality tests were performed to obtain information on physical, microbial, and chemical properties of collected water samples to address Objectives 2.a, 2.b, 2.c, 3.c, and 3.d. The specific tests and their associated water quality parameters are summarized in Table 3. After considering multiple different testing methods, the test selection was made based on their relevance to the most important water quality constituents and their appropriateness for the location mainly considering availability, ease of use in the field, and cost.

Table 3: Instruments and respective parameters for water quality tests used in the study.

Parameter Tested	Test Kit Used
Electrolytic Conductivity (EC) (in μS/cm), pH, and Total Dissolved Solids (TDS in ppm)	Hanna Instruments (Woonsocket, RI) Pocket Water Resistant EC, pH and TDS (LR) Tester HI-98129
E. Coli and Total Coliforms in CFU/mL	3M™ (Maplewood, MN) Petrifilm™ *E. Coli*/Coliform Count Plates
Total Iron in mg/L	Lovibond Tintometer (Sarasota, FL) Iron LR Checkit Test Kit

3.4. Procedures for Data Collection

Twenty-eight surveys were administered to the twenty-eight study sites in Rakai District. These twenty-eight sites have a total of thirty-three Brick by Brick constructed rainwater harvesting tanks. Twenty-four sites had one tank, three sites had two tanks, and one site had three tanks. Water samples were collected from each Brick by Brick rainwater harvesting tank at each of these sites. Before collecting the samples, the tools and instrumentation including the survey, sanitary inspection, and water quality tests were introduced to Mr. Max Ssenyonga (Brick by Brick School Program Coordinator) and Mr. David Mutesaasira (Brick by Brick Construction Manager). After minor adjustments to the survey as recommended by these two individuals, the tools were finalized (as provided in APPENDIX C and APPENDIX D).

Figure 7: Mr. Max Ssenyonga (left), Mr. David Mutesaasira (right), and Mr. James Murduca (thesis author) reviewing research tools prior to data collection.

3.4.1. Site Visits

Data were collected from May 9th, 2017 to June 29th, 2017. James Murduca and Max Ssenyonga visited each site to collect the data. Max Ssenyonga was familiar with every eligible research participant because he worked with the organization during the construction of all tanks. In addition, he is very well-known in the Rakai District. Upon their arrival at each research participant's house or institution, Mr. Murduca and Mr. Ssenyonga greeted the subjects. The project was generally introduced to them, and then the subjects were offered the consent form in their choice of either English or Luganda (both provided in APPENDIX E) to further review the project. After reviewing the project information on the consent form, the study subjects had the option to participate. After choosing to participate, a subject signed the appropriate consent form.

After completing the consent form, the survey was conducted by Mr. Murduca and Mr. Ssenyonga in an interview format. The questions (see APPENDIX C) were read directly from the survey. Answers were written as the interview was conducted. If a study participant did not understand English, Mr. Ssenyonga translated the questions into the local language, Luganda.

After completing the interview, the thesis author completed the sanitary inspection. After completing the interview and sanitary inspection, two water samples were collected from each rainwater tank in 200-mL plastic bottles. The bottles were cleaned and sanitized before each use by being placed for ten minutes in water that was immediately transferred to an insulated container directly after boiling. When collecting water samples, the water was allowed to flow from the tank outlet for twenty seconds before collection. Bottles were then transferred to a cooler before returning to the Brick by Brick Office in Kalisizo for testing. Twenty-eight surveys were collected from the twenty-eight sites, and thirty-three sanitary inspections and sixty-six water samples were collected (i.e., one sanitary inspection and two water samples for each Brick by Brick rainwater harvesting tank).

3.4.2. Water Sample Analysis

After collecting all of the samples for one day, samples were returned to the laboratory for analysis. Samples were first tested for *E. coli* and total coliforms using the 3M™ Petrifilm™ *E. coli*/Coliform Count Plates. One mL from each sample was transferred to each plate via purchased sterilized pipette. The pipettes were cleaned and sanitized before each use by being placed for ten minutes in water that was immediately transferred to an insulated container directly after boiling. After waiting one minute for the gel to solidify for each sample, the samples were then transferred to a shirt designed to hold and incubate the samples through human-body incubation provided by the thesis author. The administrative assistant Florence Nakanwagi stitched this shirt for the purpose of incubating samples. After incubating for 24 hours the samples were then analyzed by the thesis author according to 3M's interpretation guide.

After performing the microbial tests, water samples were then analyzed for iron using the Iron LR Checkit Test Kit. Ten mL of each sample were transferred into the two provided cells. Before transferring, the samples were mixed to prevent settling. One cell had a crushed iron LR tablet, and the other was used as a control. The reading of a sample's iron concentration was then made after waiting for five minutes.

After performing the iron testing, the samples were then tested for three physical water quality constituents pH, EC, and TDS using the Hanna Instruments Pocket Water Resistant electrolytic conductivity, pH and TDS (LR) Tester HI-98129. The tester's probe was directly added to the mixed 200-mL sample.

3.5. Description of Treatment Technology

The design for the *chulli* system developed for this project was inspired primarily by two previous designs, shown in Figure 8, Figure 9, and Figure 10. Both designs use excess heat from stove to disinfect influent water. The main differences from the two types of systems are the types of the stoves and the types of pipes. The *chulli* system was adapted in traditional outdoor clay ovens called *chullis* in rural Bangladesh, and the Water Disinfections Stove (WADIS) was adapted in indoor *Lorena*-stoves in rural

Bolivia. This design is similar to the *chulli* system, but it has a differences in its design. The inserted coils in the *chulli* systems were constructed from aluminum, and the inserted coils in the WADIS system were made from galvanized iron due to the availability of these selected materials.

This type of water treatment system was selected for its appropriateness to fulfill the three pillars of sustainability: social, environmental, and economic. This system fulfills the social pillar of sustainability because of the study population's general acceptance of heat disinfection as an appropriate means for treating water (they already use boiling to disinfect water), which was supported during the survey. It fulfills that environmental pillar of sustainability by reducing fuel consumption needed to boil water by eliminating the need for an excess separate fuel source for boiling. Lastly, the technology investigated in this research fulfills the economic pillar of sustainability because of its low cost and the economic savings due to a lower quantity of fuel needed. Fulfilling these three pillars supports that this technology, will be able to sustain the needs of the target population without jeopardizing the wellbeing of future populations compared to other technologies that are currently available for this purpose.

Figure 8: Overview of the entire *chulli* system (reprinted with permission of JSTOR) (Islam et. al., 2006)

Figure 9: Inside view of the *chulli* system showing the aluminum coil water flows through (reprinted with permission of JSTOR) (Islam et. al., 2006)

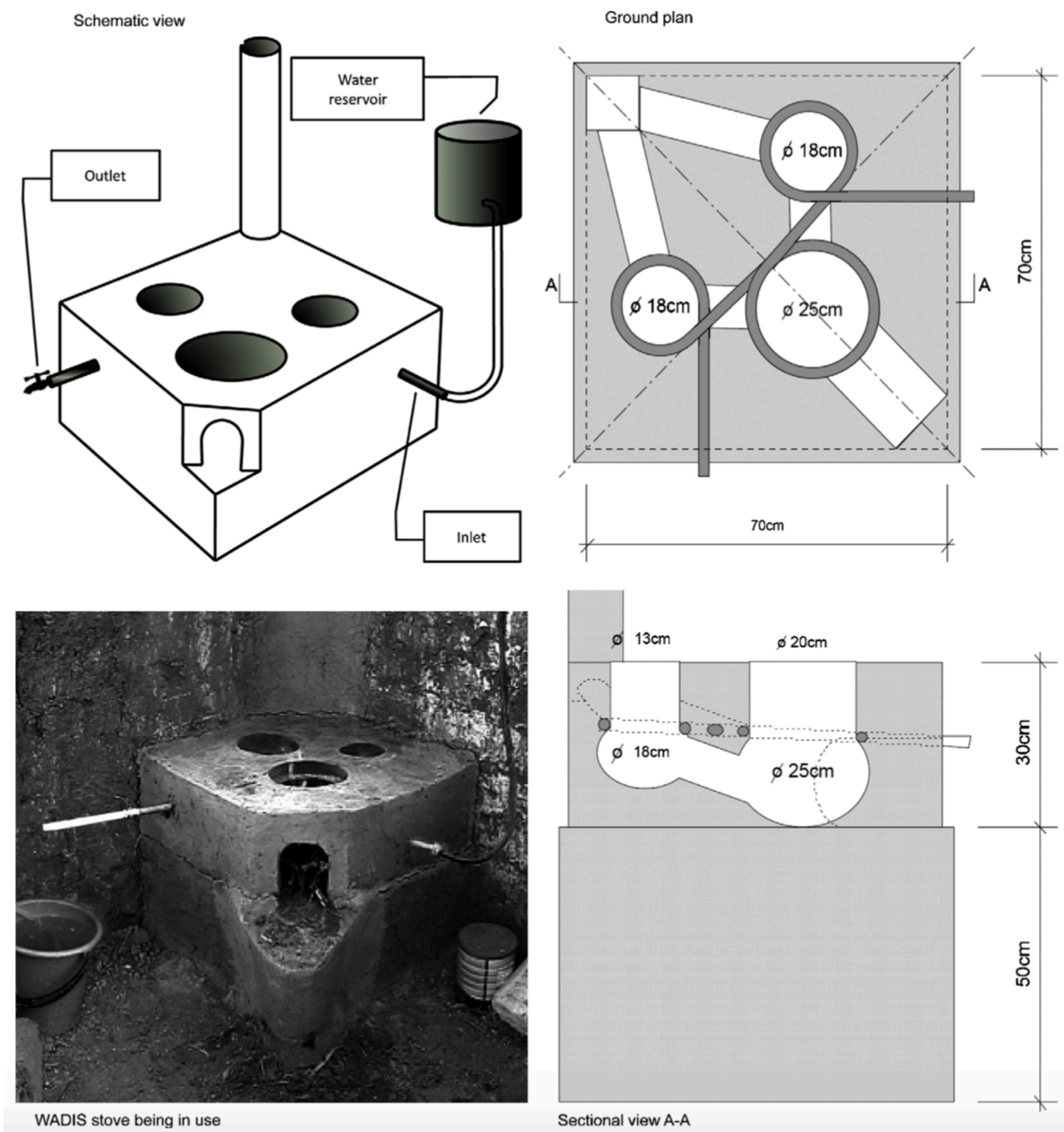

Figure 10: Design of Water Disinfection Stove (WADIS) treatment system[3]

[3] Reprinted from *Safe drinking water and clean air: An experimental study evaluating the concept of combining household water treatment and indoor air improvement using the Water Disinfection Stove (WADIS)*, 212/5, Andri Christen, Carlos Morante Navarro, Daniel Mäusezahl, *International Journal of Hygiene and Environmental Health*, 562-568, Copyright (2018), with permission from Elsevier.

The *chulli* system treats water by both filtration and heat disinfection. As shown in Figure 8, the raw water first passes by gravity through a rapid sand filter located above the outlet of the *chulli* system. The water then travels by gravity to the stove, in which it is treated in a heat-exchanging coiled pipe (Figure 8, Figure 9, and Figure 10). The water then passes through the outlet to the tap at an effluent temperature of 70 ºC from which the treated water is collected. These systems have been effective at removing all *E. coli* from previous case studies (Christen et. al., 2009; Islam et. al., 2006); however, limitations of the system including poor durability, inconvenience, high cost, and post-treatment contamination have prevented the widespread use of the system. In order to address this potential conflict, Brick by Brick's team provides training for repairing the system themselves and direct hands-on assistance for repair. The clients are also informed on how to use the system properly after installation.

The treatment technology for this project was adapted from the *chulli* and the WADIS systems incorporating the local material and stove designs. For this project's specific treatment system, the thesis researcher used locally available resources and Brick by Brick's fuel-efficient stove design. Given the dimensions of Brick by Brick's fuel-efficient stoves and the availability of different construction materials in the greater Masaka area, the design for this location was further developed by the thesis author.

The design tested for this research included a half-inch galvanized iron pipe coiled with 1.75 rotations. The coil had a 12-inch diameter. This pipe was then inserted into the fuel-efficient stove. It was fed from a 60-L plastic storage reservoir containing the untreated rainwater. Water is fed through this system during cooking. The flow rate could be adjusted by the tap until a desired outflow temperature is achieved. When the effluent water from the tap (Figure 10) is too hot to touch, the water could start being collected. After cooling through heat transfer in the storage container, the water can be used for potable purposes.

3.6. Data Analysis

Data were analyzed using descriptive statistics including frequencies and percentages were computed from the collected data. Associations between independent and dependent variables in regards to knowledge, attitude, and practices were computed using appropriate nonparametric tests due to the small study population (n=28) and sample population (N=28).

CHAPTER 4: RESULTS AND DISCUSSION AND RECOMMENDATION FOR FUTURE RESEARCH

This section contains the results from the data collection and analyses that address the study hypotheses and objectives.

4.1. Sample Description

Twenty-eight surveys were administered to the twenty-eight sites in the study population. The distribution for the classification of these sites (i.e., household, school, hospital) is provided in Figure 11. As shown, eighteen of the sites are families, and the other ten are institutions (nine schools and one hospital). The average number of people being served by Brick by Brick rainwater harvesting tanks for different age categories at each site by classification is shown in Table 4. As shown in this Table 4, 1.9, 25, and 20 children under five are being served by the Brick by Brick rainwater harvesting tanks on average at family, school, and hospital sites, respectively. Nineteen of the twenty-eight sites have children under five being serviced by the rainwater, and fourteen of the twenty-eight sites have adults over the age of sixty being serviced by the rainwater harvesting tanks. This is important because infants and young children and the elderly are considered at greatest risk of waterborne diarrheal disease (WHO, 2011).

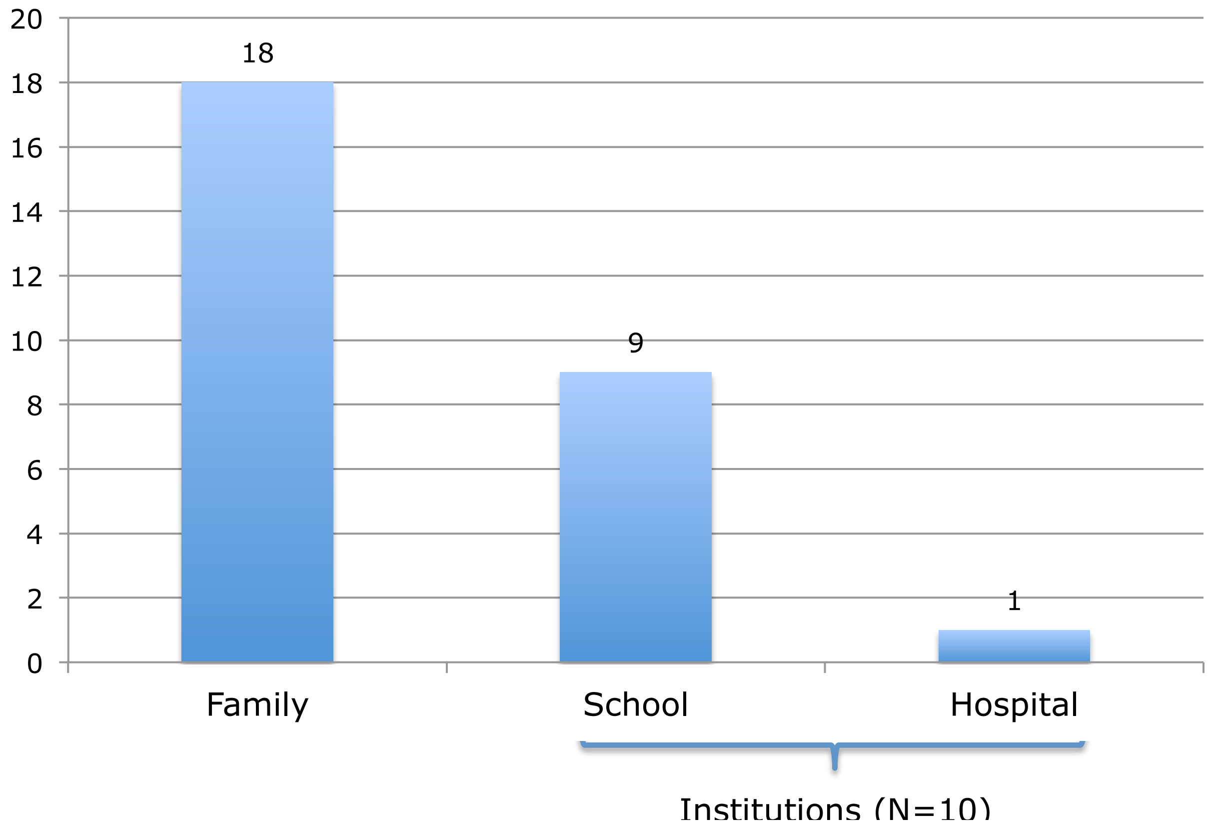

Figure 11: Study site classification distribution showing number of families, schools, and hospitals served by Brick by Brick rainwater harvesting tanks

Table 4: Average number of people for different age categories being served by Brick by Brick rainwater harvesting tanks at each site classification.

		Age (# of years)			Total
		0-5	6-60	61 or greater	
Residential	Households	1.9	12	0.83	15
Institutions	Schools	25	410	0.44	430
	Health center*	20	59	10	100
*Only one health center was included; therefore, these numbers are the representative number of people being served by the tanks at this site.					

The thirty-three[4] sanitary inspections and water quality tests were performed. The distribution for the classification of inspected and tested tanks by storage capacity is shown in Figure 12. The tank capacities range from 10,000 L to 60,000 L with a majority of them (nineteen of thirty-three) being 10,000 L. One *chulli* system was fabricated as a demonstration for a school not included in the twenty-eight sites in the study population. This location was chosen in order to trial and assess the performance of the treatment technology before constructing the system for the two raffle winners from the twenty-eight sites in the sample population.

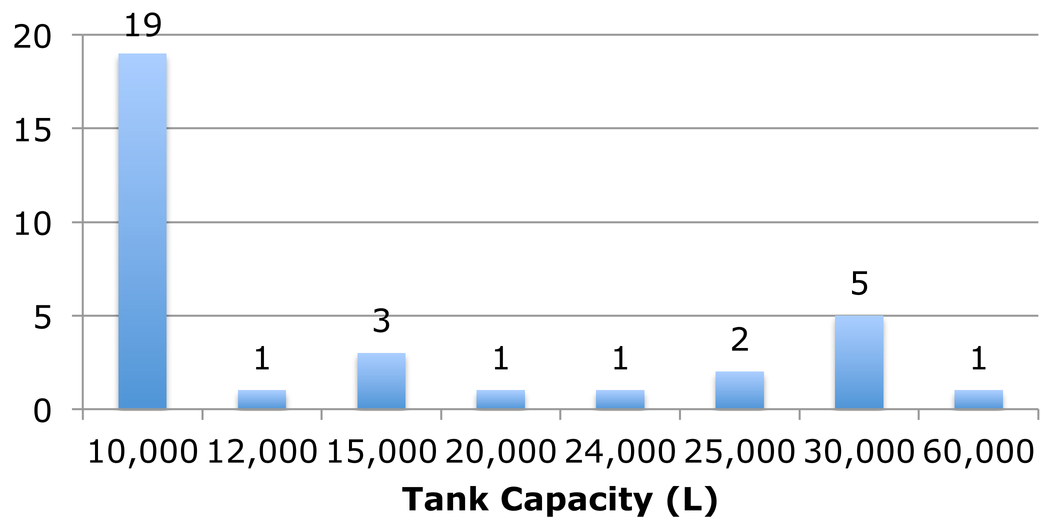

Figure 12: Distribution of the capacities of the thirty-three[4] Brick by Brick rainwater harvesting tanks, for which the sanitary inspections and water quality tests were performed.

[4] Some sites have more than one Brick by Brick rainwater harvesting tank. Sanitary inspections and water quality tests were performed for each Brick by Brick rainwater harvesting tank. Therefore, there are more sanitary inspections (N=33) and water quality tests (N=33) than total sites (N=28) and surveys (N=28).

4.2. Knowledge, Attitudes, and Practices of Drinking Water Management in Regards to Public Health

This section describes the key findings from the analyzed data in regards to public health. All respondents (n=28) reported that the populations at their site use the rainwater for drinking purposes. Twenty-four sites (n=28) reported rainwater as their primary drinking water source, and the four remaining sites reported piped water as their main drinking water source. The four sites that reported piped water as their main drinking source reported rainwater as their secondary drinking water source. These four sites are schools. All sites except two primary schools that use rainwater as their primary drinking water source reported treating their water before consumption. Table 5 summarizes the frequencies of these different treatment methods. The two sites that reported not treating their rainwater before consumption were asked to explain why they chose to not treat water. Both sites reported that it was too expensive, and one reported that it required too much time.

Table 5: Frequencies of different water treatment methods by users of Brick by Brick Rainwater Harvesting Tanks having reported treating their water before consumption (n=26).

Boiling	Boiling + Filtration	Chlorine	Settling	Filtration	Total
20	3	1	1	1	26

Participants were asked, "What are the possible causes of diarrhea?" to address whether or not the perceived contaminated drinking water could be a cause of diarrhea. Participants were able to choose all the responses that apply. Figure 13 demonstrates the distribution of responses for this question. As shown, twenty-four of the twenty-eight respondents noted that contaminated water could be a cause of diarrheal diseases. In addition, twenty-one of the twenty-eight respondents reported that lack of hand washing could be a cause of diarrheal disease. No respondents indicated microbial pathogens as a cause of diarrheal disease. This may be because of the respondents' unfamiliarity with the specific term "microbial pathogens" or the lack of knowledge of these as microbial contaminants. The two respondents who reported not treating their water, reported contaminated food, contaminated water, and lack of hand washing as responses to this question. This shows that these respondents were aware of the potential risk of diarrhea caused by contaminated water.

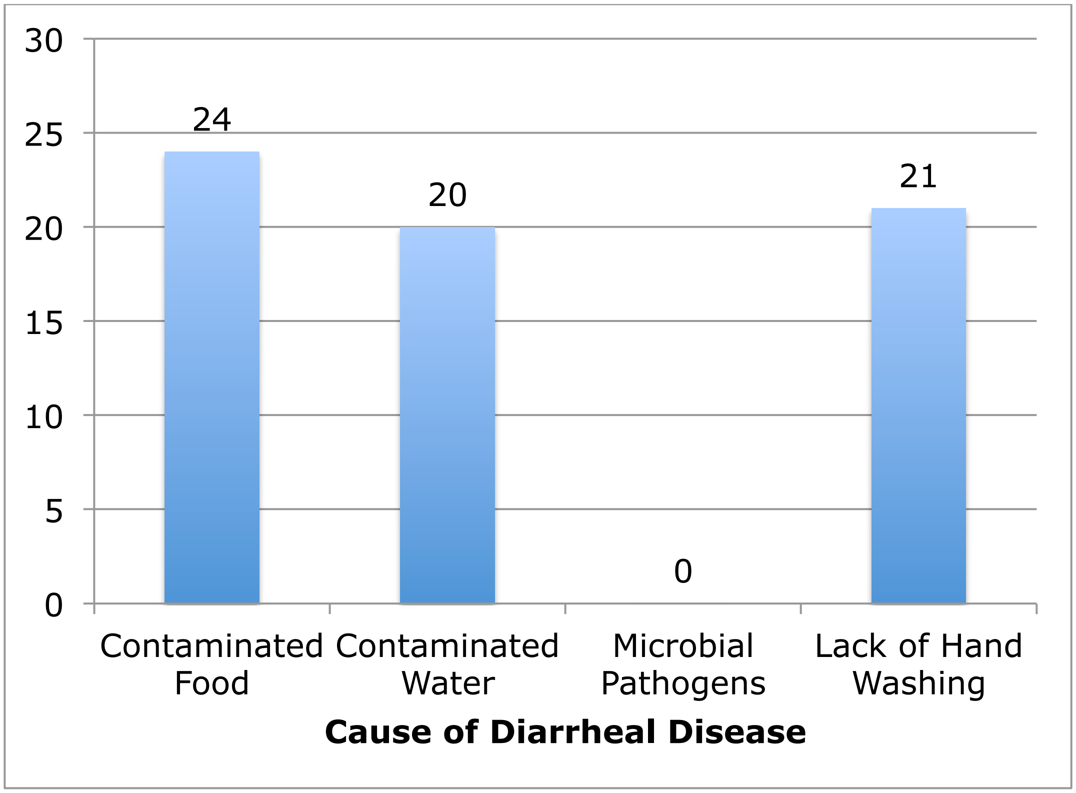

Figure 13: Distribution of responses to the question "What are the possible causes of diarrheal disease?" for users of Brick by Brick rainwater harvesting tanks in Kalisizo (N=28)

Participants were asked to rank the top three perceived ways of treating water. The thesis author originally included this question to identify the top three water treatment methods according to the research participants. He found that not all participants were able to name three water treatment methods. This suggests that research participants were less aware of different methods of treating water than originally expected. Fourteen of the twenty-eight participants were able to identify three ways of treating water. Eight were able to identify two ways of treating water. Six were able to identify one way of treating water. Table 6 shows the different frequencies for the rankings of these different types of treatment methods. As shown, twenty-seven of the twenty-eight respondents identified boiling as the best way of treating water. The remaining respondents identified boiling as the third best way of treating water. This shows that all respondents were at least familiar with boiling as a water treatment method, with twenty-seven out of twenty-eight identifying it as the best method suggesting that the respondents see boiling as an effective means of treating water. In regards to introducing new sustainable water treatment methods, this information suggests that a heat treatment solution similar to boiling would be accepted more readily than other methods.

It is important to note that none of the respondents identified SODIS among the top three treatment methods. Given the effectiveness, cost, environmental impact, and plausibility of SODIS for this location, none were aware of it. The thesis author identified four cases referencing the usage of SODIS as a water treatment technology in Uganda. The first case included SODIS as an intervention in response to a cholera outbreak in Busia District (Water School Uganda, 2017). The second was the promotion of the WADI (a technology used to identify a sufficient exposure of ultraviolet for SODIS treated water) produced by Helioz at a Uganda Water and Sanitation Network (UWASNET) conference in October 2016. The third was the thesis author's personal use of SODIS as his daily treatment method along with filtration. Last, John Trimmer, the Brick by Brick volunteer who served before the thesis author, used this as his drinking water treatment method. SODIS is an inexpensive option for these participants, but a lack of awareness and knowledge of this treatment method may be a reason for a lack of use. In addition, the treated water produced is limited by the size of the container. For larger families or communities, many bottles would need to be used in order to produce larger volumes of water. In order for people to adopt this treatment method, further promotion and education may be required. In addition, six participants identified safe storage as a treatment method.[5] Although safe storage does not remove contaminants from water, it does prevent recontamination. These responses suggest that these survey participants are aware of this safe practice to improve health conditions.

Table 6: Frequencies of ranks of perceived best water treatment methods by survey respondents

	Treatment Method				
Rank	Boiling	Chlorine	Filtering	Safe Storage	Distillation
1 (best)	27	0	1	0	0
2	0	11	8	1	2
3	1	5	1	5	2

[5] John Trimmer treated his water using the same method as the thesis author; however, both were unaware of this until coincidentally discussing the topic on one of John Trimmer's visits to Uganda and Brick by Brick in Spring 2017.

4.3. Sanitary Inspections

Thirty-three sanitary sections were administered. Table 7 shows the results for the sanitary inspections. Sanitary inspections, APPENDIX D, were scored from 0, low risk, to 10, high risk, to assess the risk of contamination.

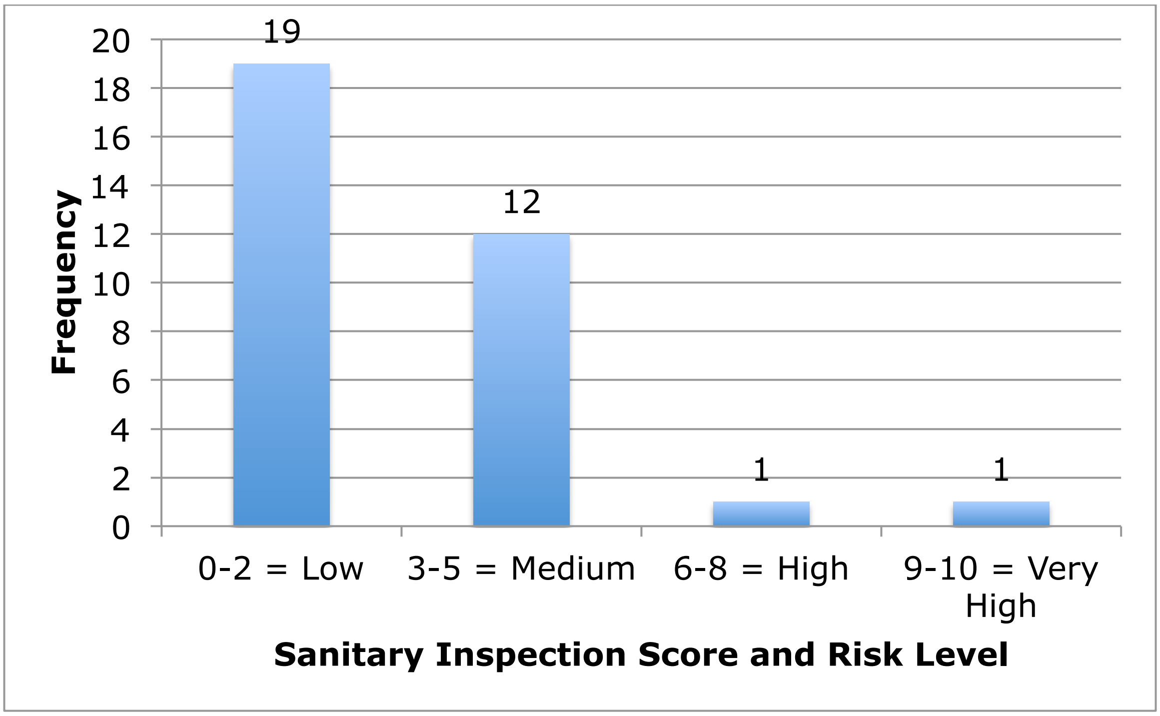

Figure 14: Frequencies of sanitary inspection scores according to their respective risk levels for the Brick by Brick rainwater harvesting tanks (n=33).

Figure 14 shows the frequencies of scores according to their respective health risk levels. As shown in Table 7, the average risk level score for the rainwater harvesting is 2.27, which places it between a low and medium risk level.

Table 8 shows the frequencies of potential risk based on observation from the sanitary inspection (inspections are provided in APPENDIX D). The top three frequent risk observation areas from Table 8 were "problems with the filter box or first flush system at the tank inlet" (n=19), "the water collection area inadequately drained" (n=15), and "the concrete floor under the tap missing, broken or dirty" (n=11). All of the risk observation areas are outside of the house and in proximity to rainwater harvesting tank. This suggests that these areas should be emphasized for maintenance when monitoring current and installing new rainwater harvesting systems.

Table 7: Results summary for the sanitary inspections found in APPENDIX D for the thirty-three administered Brick by Brick rainwater harvesting tanks.

Minimum Possible Score	Maximum Possible Score	Minimum Administered Score	Maximum Administered Score	Average Score	Standard Deviation
0	10	0	10	2.27	2.31

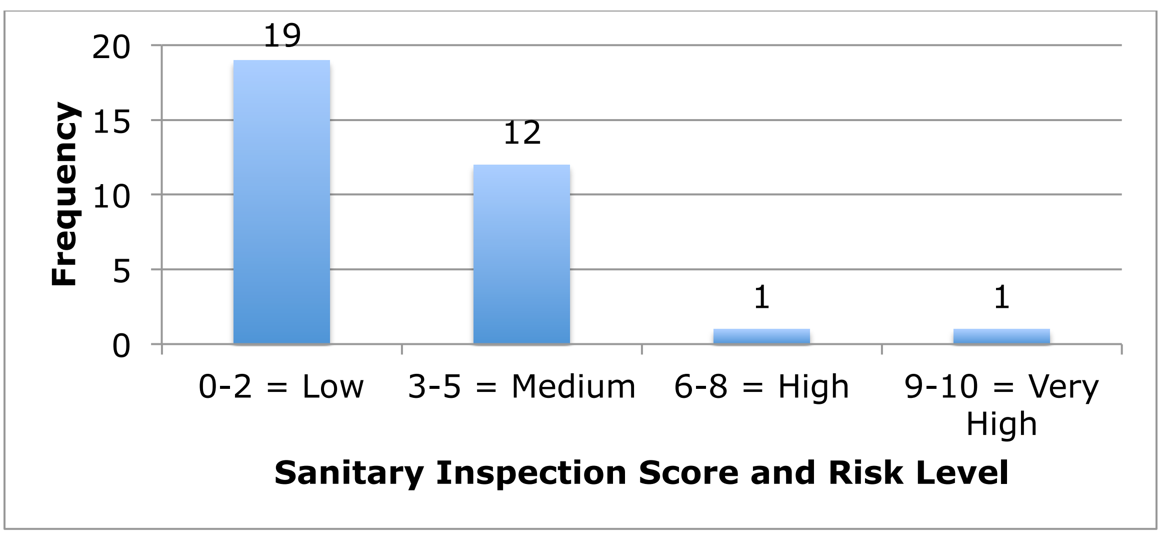

Figure 15: Frequencies of sanitary inspection scores showing the observed potential health risk for the Brick by Brick rainwater harvesting tanks (n=33).

Table 8: Frequency of potential risk observation based on sanitary inspection found in APPENDIX D, (n=33).

Observation	Frequency of Risk Observation
Are there visible signs of contamination on the roof (e.g., feces, dirt, leaves)?	2
Is the gutter system that collects rainwater dirty or blocked?	2
Are there any problems with the filter box or first flush system at the tank inlet?	11
Is there any other point of entry to the tank that is not properly covered?	6
Is the top or wall of the tank cracked or damaged?	5
Is the tap leaking or broken?	2
Is the concrete floor under the tap missing, broken or dirty?	19
Is the water collection area inadequately drained?	15
Is there any source of contamination around the tank or water collection area?	7
Is a bucket in use and left in a place where is may become contaminated?	6

4.4. Results of Water Quality Analyses

Thirty-three water samples were collected from the thirty-three Brick by Brick rainwater harvesting tanks in the Rakai District in Uganda. Table 9 summarizes the water quality results. Table 10 shows the frequencies of positive and negative results for total coliforms and *E. coli*. This information demonstrates a presence of coliform bacteria in fourteen of the thirty-three tested tanks. In the remaining nineteen tanks, no detected colony forming units were identified. As noted in the literature review, rainwater quality varies in different locations and many different factors including system management and maintenance contribute towards the water quality (Gwenzi et. al., 2015). These results show no abnormalities for the physico-chemical results. Figure 16 shows a sample water quality test from this study indicating no presence of colony forming units of coliform bacteria or *E. coli*. Figure 17 shows a sample water quality test from this study indicating a presence of colony forming units of both coliform bacteria (red colony forming units with associated gas bubbles) and *E. coli* (blue colony forming units with associated gas bubbles).

Table 9: Water quality results summary for the sampled Brick by Brick rainwater harvesting tanks in Rakai District (n=33)

Parameter	Mean	Standard Deviation	CI, 95%
pH	7.46	1.02	0.35
TDS (ppm)	18	8.17	2.79
Electrolytic Conductivity (μS/cm)	35	16	5.5
Total Coliforms (CFU/mL	2.33	4.95	1.69
E. Coli (CFU/mL)	0.09	0.38	0.13
Iron (mg/L)	(below detection level)	(below detection level)	N/A

Table 10: Frequencies of presence and absence results for total coliforms and *E. coli.* for tested samples from Brick by Brick rainwater harvesting tanks in Rakai District (n=33)

	Total Coliforms (cfu/mL)	*E. coli* (cfu/mL)
Absence	19	31
Presence	14	2

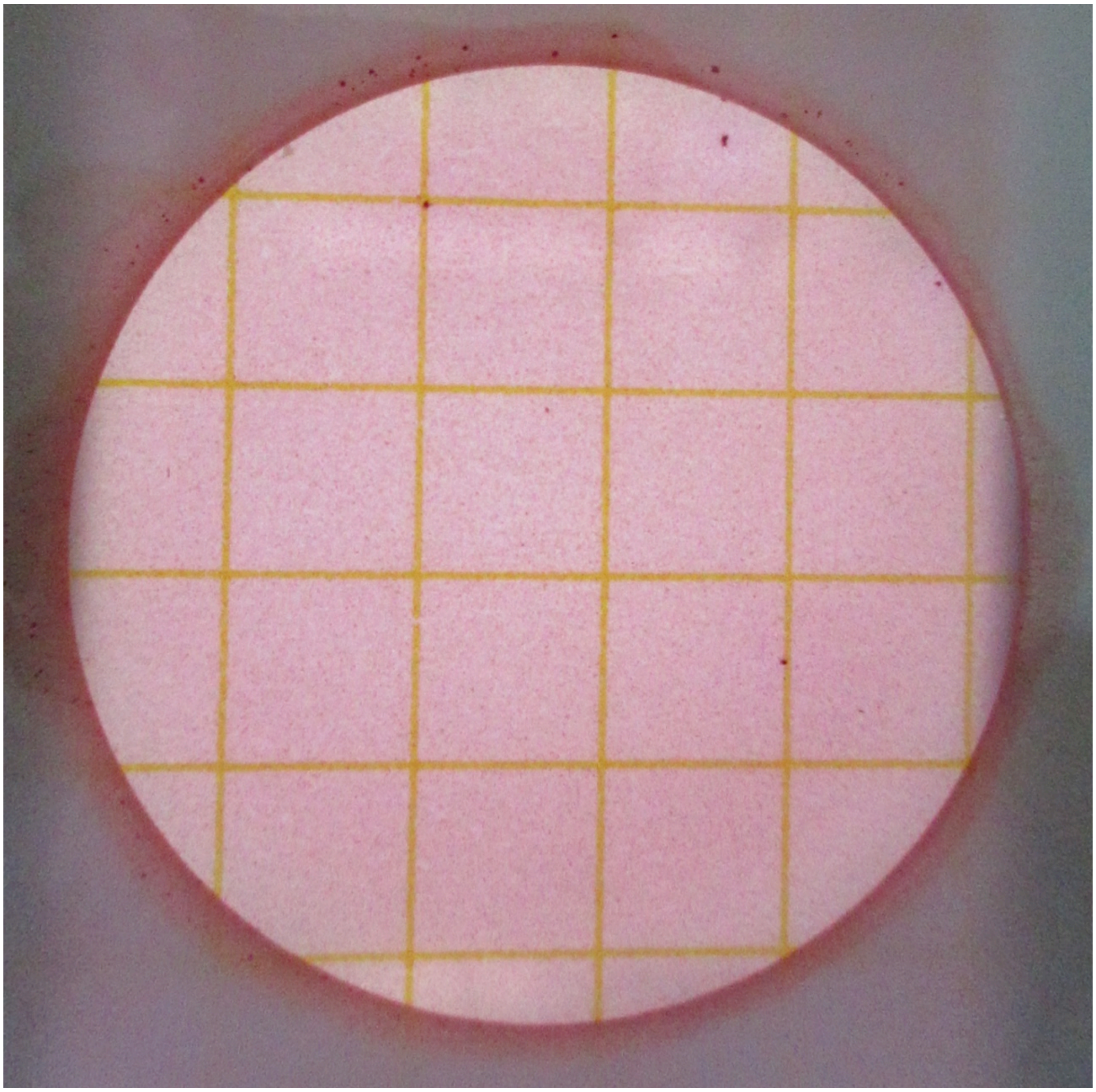

Figure 16: Example water quality test result for a Brick by Brick rainwater harvesting tank sample representing no indication of any colony forming units of coliform bacteria or *E. coli* for the 1 mL given that no red or blue colonies with associated gas bubbles were found.

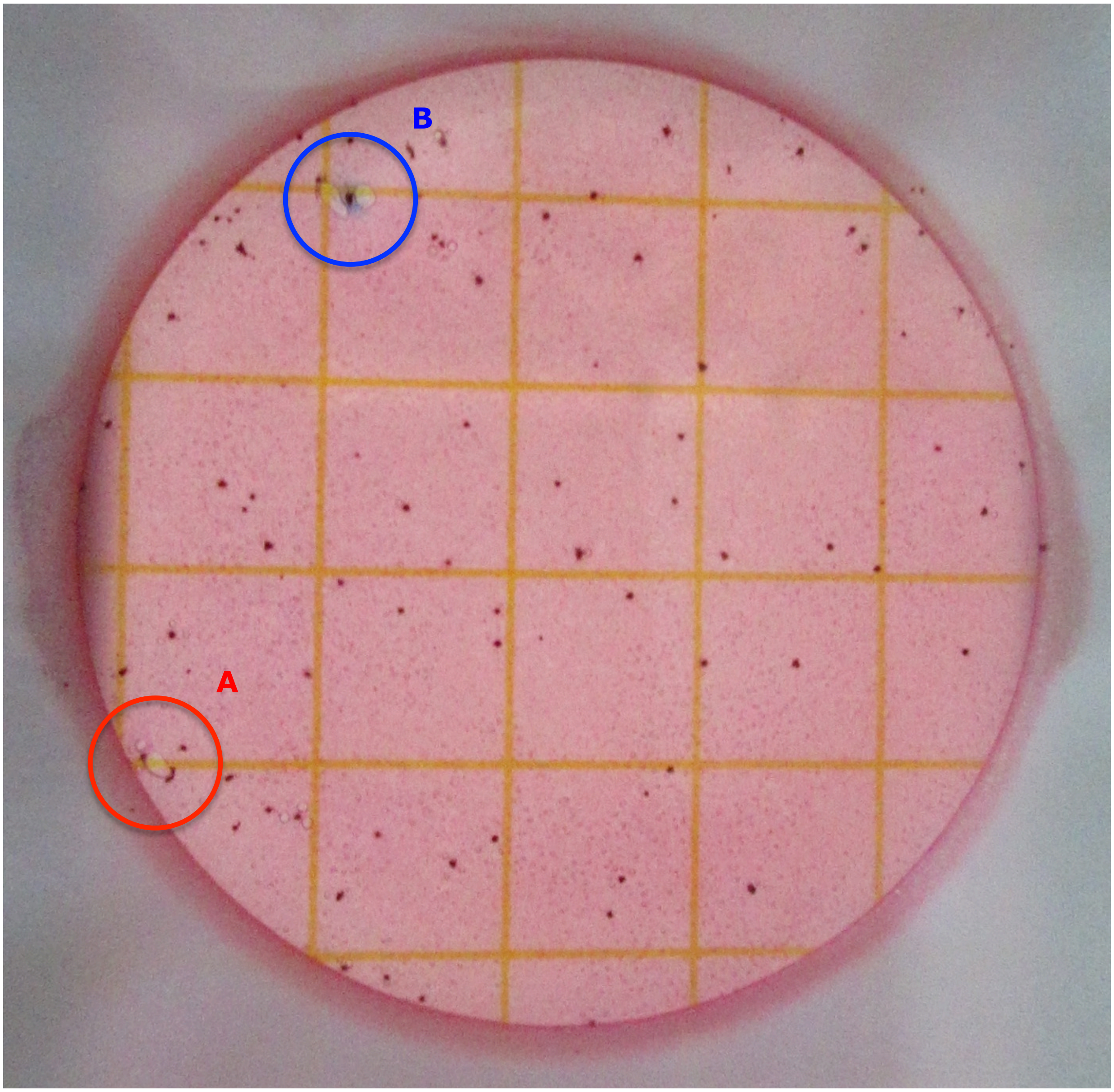

Figure 17: Example water quality test result for a Brick by Brick rainwater harvesting tank sample representing a positive indication of colony forming units of coliform bacteria or *E. coli* for the 1 mL given that both red (A) and blue (B) colonies with associated gas bubbles were found.

It is important to note that the sample volume for the total coliform and *E. coli* tests was 1 mL and that one test was conducted for each tank. It is possible that replicate tests or tests conducted with higher sample volumes would detect a larger number of samples with a presence of colony forming units for coliform bacteria or *E. coli*. For example, one study used this test three times for each water sample taken and averaged the results (Stepenuck et. al., 2011). In this example, it is possible that colony-forming units would be present on one of tests and not present on two of the tests. Therefore, replicate tests for this study could have yielded a larger number of samples with a presence of coliform bacteria and/or *E. coli*. Nonetheless, the positive samples for this stuffy still show a presence of the indicator bacteria and a possible health risk.

This study identifies cases of rainwater with the presence of indicator bacteria. Although some of the rainwater samples showed the presence of microbial species, these sources may still be more advantageous than other sources such as surface water due to the proximity, availability, and relative water quality. Furthermore, the results detected a lower percentage of positive samples than the cases presented in Table 2.

4.5. Comparison of Sanitary Inspection Score Versus Water Quality Tests

Table 11 shows the comparison between water quality test results and sanitary inspection scores. The sanitary inspection scores were generated from the outdoors risk observation areas detailed in APPENDIX D. Table 11 demonstrates the percentages of water samples detecting either coliforms or *E. coli* in each respective sanitary inspection results category. For example, nineteen sanitary inspections received scores in the 0-2 range, and seven of the nineteen respective water quality samples had detectable levels of coliforms. Therefore, 37% of the sites that received scores ranging from 0-2 in the sanitary inspection also had coliforms detected for their water quality results. The most significant finding from these results is the increase in percentage of nonzero samples for total coliforms in the 0-2 and 3-5 ranges. As shown, the percentage of the sites that had coliforms detected in their water quality results increases from 37 for respective sanitary inspection scores in the 0-2 range to 50 for respective sanitary inspection scores in the 3-5 as expected. This suggests that a higher sanitary inspection score correlates with a detectable value of total coliforms for these score ranges. This trend is not consistent for the 6-8 and 9-10 ranges; however, only one sample was available for each of these categories. A higher number of samples could have provided a more representative result. For the *E. coli* results, positive samples were only found in the 0-2 inspection score range. These findings are unlikely to be significant because only two of the thirty-three total samples were found to be positive for *E. coli*. A larger sample would inform more significant results.

Table 11: Percentages of water samples with detectable concentrations of either coliforms or *E. coli* in each respective sanitary inspection results category for the Brick by Brick rainwater harvesting tanks in the Rakai District (n=33).

	Sanitary Inspection Score			
	0-2 (low risk)	3-5 (medium risk)	6-8 (high risk)	9-10 (very high risk)
% of samples with detectable concentrations of Total Coliforms	37	50	0	100
% of samples with detectable concentrations of *E. Coli*	11	0	0	0

The effectiveness of the first flush system for improving water quality in rainwater harvesting systems for this project was analyzed. Table 12 shows a comparison of the percentages of samples measured to have detectable levels of total coliforms and *E. coli* for systems that were identified by the sanitation inspection to have issues with the first flush. Two common issues with the first flush systems were identified during the sanitary inspections. Some users did not know how to empty their first flush systems and consequently did not perform this necessary task, and some rainwater harvesting systems did not have first flush systems. As shown in Table 12 the percentage of samples with detectable levels of total coliforms is higher, 55% versus 36%, for rainwater harvesting systems identified to have a problem with the first flush system.

Table 12: A comparison of the percentages of samples with detectable levels of indicator bacteria for systems with issues with the first flush system for both total coliforms and *E. coli*.

	% of samples with detectable levels of indicator bacteria and a problem with first flush system	% of samples with detectable levels of indicator bacteria and a problem with first flush system
Total coliforms	36	55
E. coli	9	0

4.6. Treatment Technology

This study aimed to determine the appropriateness of the *chulli* system as a treatment method for the sample population and evaluate its performance. This section discusses these two subjects.

4.6.1. Appropriateness of Treatment Technology

The *chulli* system operates when someone cooks using firewood as a fuel source. All of the respondents (n=28) reported using firewood as a fuel source for at least one cookstove. All respondents (n=28) reported having a type of cookstove. This demonstrates that each site already has a stove that uses the same fuel source, wood, required for the *chulli* system to function. A description of the operation procedure of the *chulli* system was provided previously in Section 3.5.

The system also uses heat disinfection to treat the water. As shown in Table 6, all respondents had ranked boiling (a heat disinfection treatment method) one of the top three methods they are aware of for treating water. In fact, twenty-seven of the twenty-eight respondents ranked it as the best choice for treating water. This suggests that the sites may find this system an effective means of treating water because it uses heat for treatment.

Hypothesized advantages of this system were that it would save beneficiaries time by eliminating the need to boil water and cook separately and money by using only one fuel source for both boiling and cooking at the same time. These hypotheses were analyzed. Figure 18, Figure 19, Figure 20, and Figure 21 summarize the results of these analyses. Figure 18 shows the mean time households and institutions spend boiling water with 95% confidence interval for the households (n=17) and institutions (n=6) that boil their water. Figure 19 shows the mean percentage of total daily cooking time spent on boiling water with a 95% confidence interval for the households (n=17) and institutions (n=6) that boil their water. Figure 20 shows the mean monthly spending on fuel for boiling for households and institutions that boil their water with a 95% confidence interval for the households (n=16) and institutions (n=6) that boil their water. Figure 21 shows the mean percentage of monthly spending on fuel for boiling for households and institutions with a 95% confidence interval for the households (n=16) and institutions (n=6) that boil their water. As shown in Figure 18, Figure 19, Figure 20, and Figure 21, the treatment technology would reduce a significant amount of time (approximately 25 minutes per day and 23% of the total stove usage time for the seventeen included households and 58 minutes per day and 25% of the total stove usage time for the six included institutions) spent boiling and monthly monetary spending (approximately 13,188 UGX per month and 21% of the total fuel cost for the sixteen households and 61,500 UGX per month and 25% of the total fuel cost for the six institutions) on fuel for boiling.

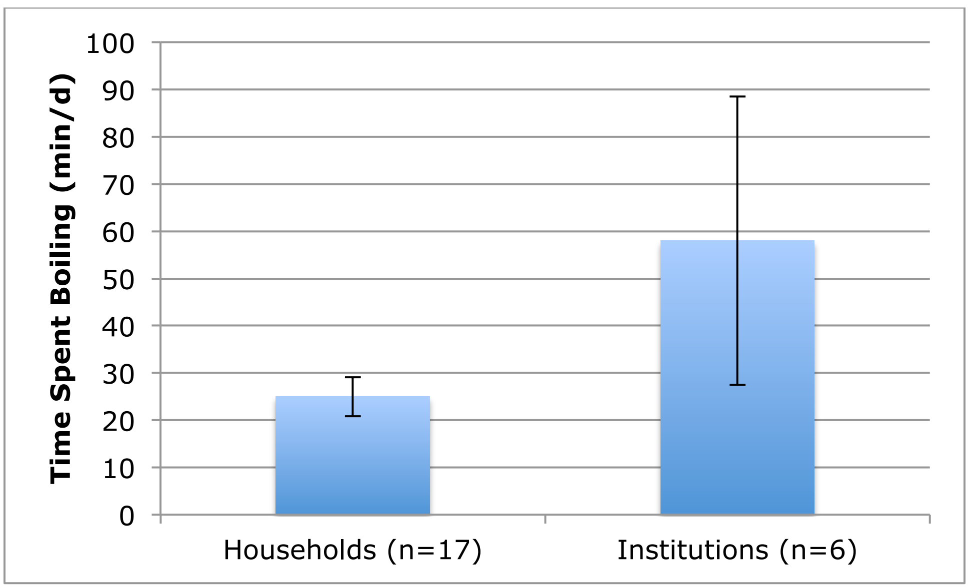

Figure 18: Mean time in minutes households and institutions spend boiling water with 95% confidence interval for the households (n=17) and institutions (n=6) that boil their water

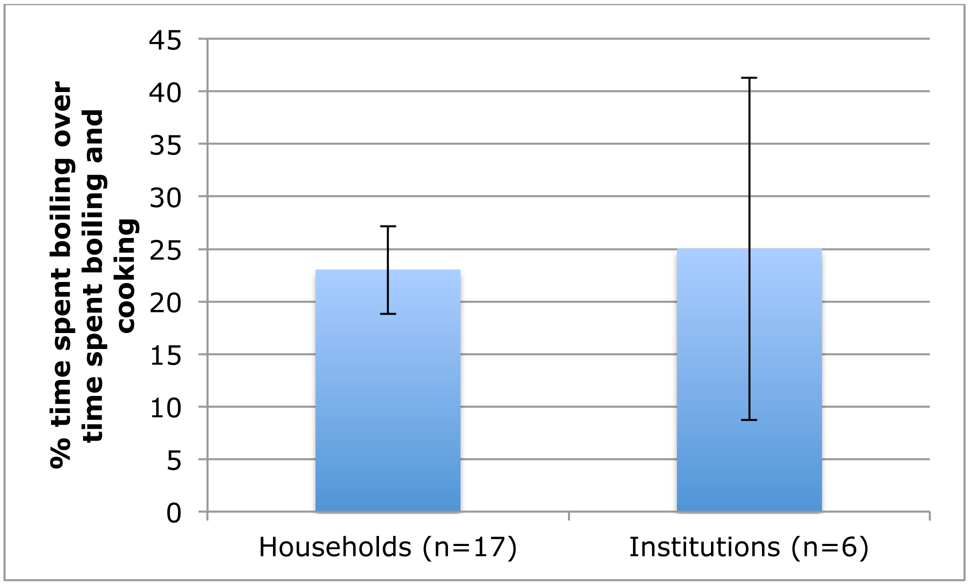

Figure 19: Mean percentages of total daily cooking time spent on boiling water with a 95% confidence interval for the households (n=17) and institutions (n=6) that boil their water

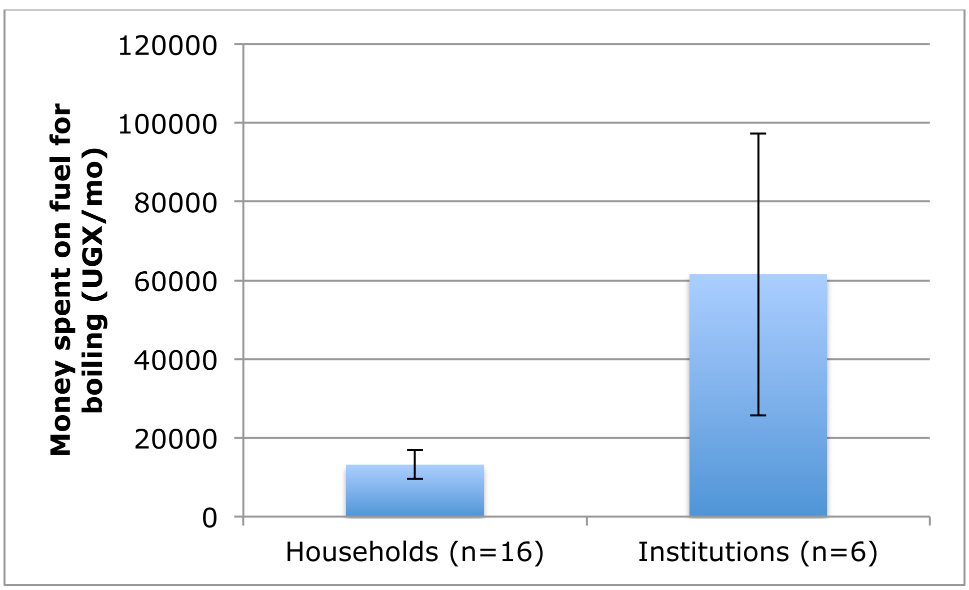

Figure 20: Mean monthly spending in Ugandan shillings (UGX) on fuel for boiling for households and institutions that boil their water with a 95% confidence interval for the households (n=16) and institutions (n=6) that boil their water

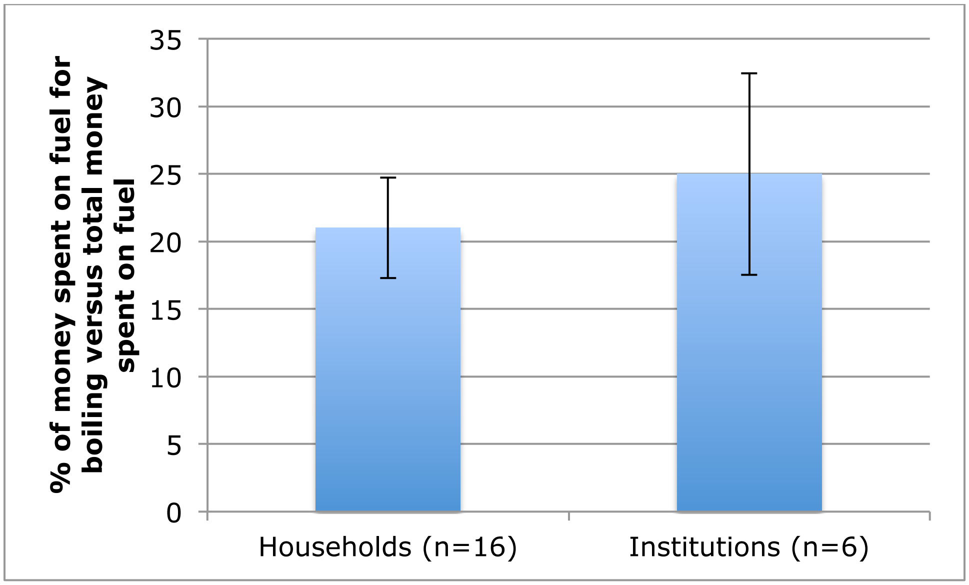

Figure 21: Mean percentage of monthly spending on fuel for boiling for households and institutions with a 95 % confidence interval for the households (n=16) and institutions (n=6) that boil their water.

Note that for the households for the time analysis, data points from one household applied in Figure 18 and Figure 19 were removed from the analysis due to the quantity of people at the household being served by daily cooking. The time for cooking for the household was reported to be 420 minutes per day, which over four times the average for households. For the households for the economic analysis, another household set of data points were removed because they used electricity for boiling as opposed to firewood for boiling.

The data collected considering daily time spent cooking and the volumetric flow rate (500 mL/min) of the *chulli* system were analyzed to determine the yield of treated water from the *chulli* system. Figure 22 shows the mean possible daily volume of treated water (in liters) that households and institutions can process with the *chulli* system with a 95% confidence interval for households (n=17) and institutions (n=6) based on daily time spent cooking. As shown in Figure 22, the *chulli* system would yield approximately 45 liters per day on average for each household and approximately 125 liters per day on average for each institution.

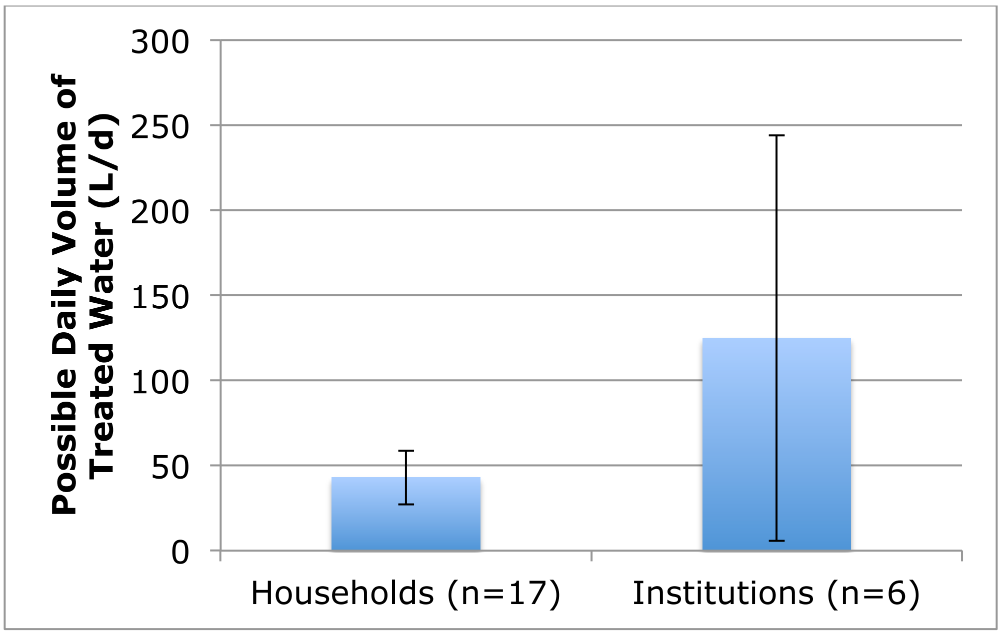

Figure 22: Mean possible daily volume in liters of treated water that households and institutions can yield by using the *chulli* system with a 95% confidence interval for the households (n=17) and institutions (n=6) based on daily time spent cooking.

The data collected that considered the mean possible daily volume of treated water and mean price of fuel for cooking per month were analyzed to determine the volume of water treated per price of fuel from the *chulli* system. Figure 23 shows the mean volume of water treated per price of fuel (in liters per thousand Ugandan Shillings) for households and institutions. As shown in Figure 23, the *chulli* system would yield approximately 24 liters of processed water per thousand Ugandan Shillings for the households and approximately 17 liters of processed water per thousand Ugandan Shillings for the institutions.

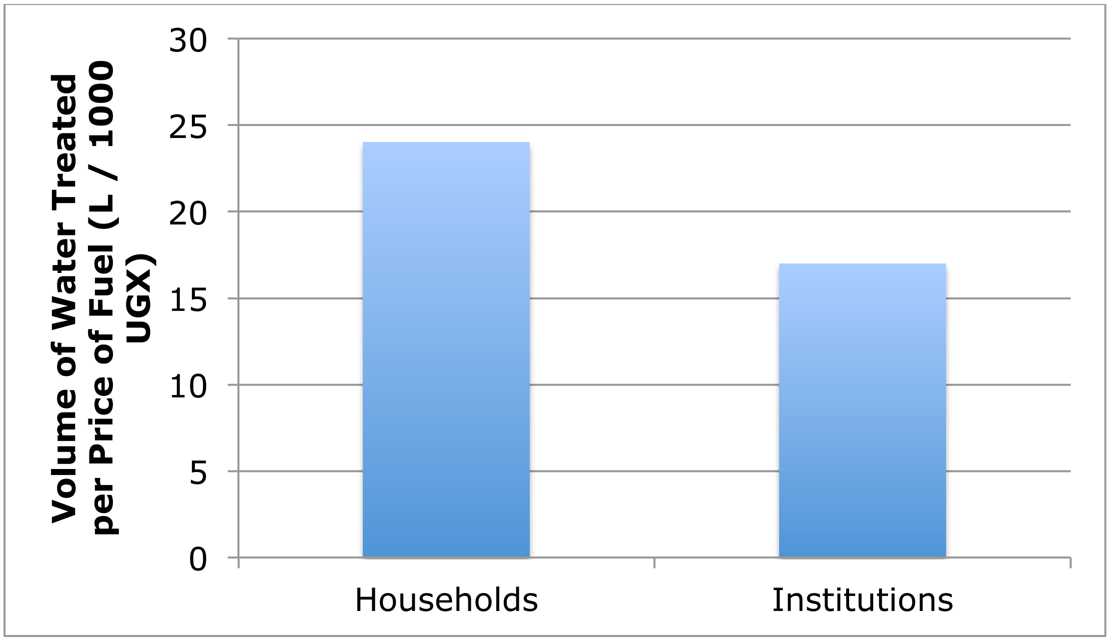

Figure 23: Mean volume of water treated per price of fuel in liters per thousand Ugandan Shillings for households and institutions.

In terms of prices, the Brick by Brick fuel-efficient stove costs approximately 500,000 UGX (140 USD) with the installation of the *chulli* system; the *chulli* system add-on is approximately 220,000 UGX (60 USD) at the time this research was performed. Therefore, the whole system will cost 720,00 UGX (200 USD). The cost has some variance due to the different possible designs of each stove and *chulli* system that mainly consider the fixed size of the saucepan area. Figure 24 shows an analysis of the upfront cost of the *chulli* system upgrade versus saved value of water based on the monthly spending of fuel for boiling water for households and institutions.

As shown, households and institutions would begin saving money on the *chulli* system after months sixteen and three, respectively.

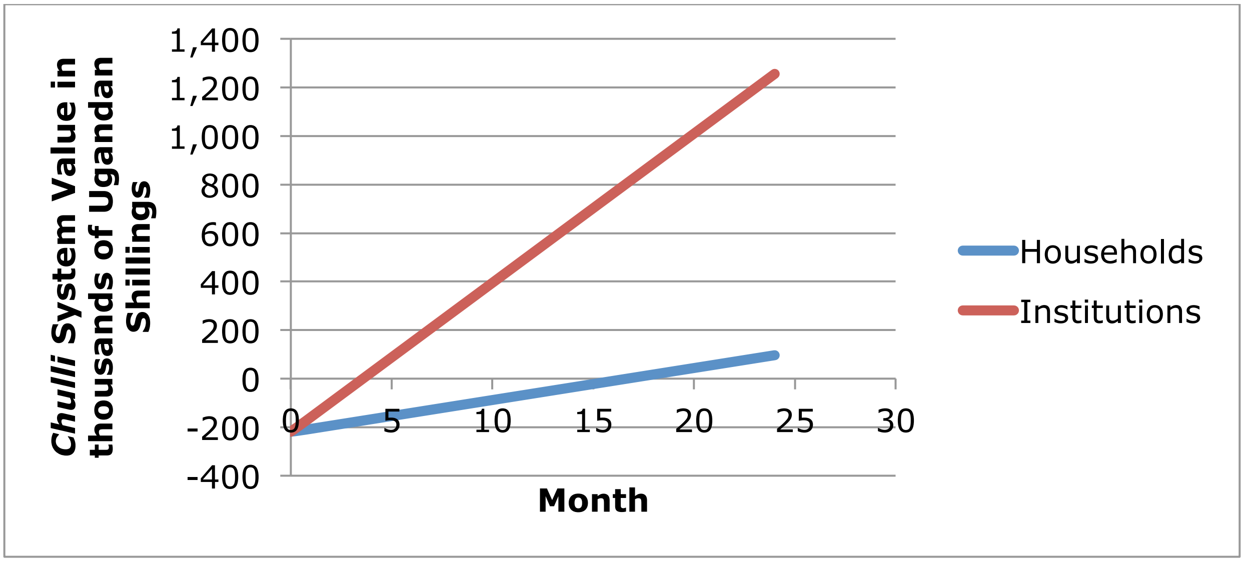

Figure 24: Analysis of upfront cost of the *chulli* system upgrade versus saved value of water based on the monthly spending of fuel for boiling water for households and institutions.

An economic analysis was performed for the *chulli* system for households and institutions to show its future value demonstrated in Figure 25 and Figure 26, respectively. Standard engineering formulas were used to develop these results. For both households and institutions, the present value was the cost of *chulli* system add-on (220,000 UGX). For households, the gradient amount was a value of 158,256 UGX annually, which was calculated from the monthly savings from the *chulli* system for households. For institutions, the gradient amount was a value of 738,000 UGX annually, which was calculated from the monthly savings from the *chulli* system for institutions. For both households and institutions, a range of interest rates from 1% to 20% was included. For households, future years from 2 to 3 years in 0.25-year increments were included. For institutions, future years from 1 to 2 years in 0.25-year increments were included. These were included because their lower and upper limits show negative and positive future values, respectively. The lifespan of these types of cookstoves ranges and depends on multiple factors. One study found that the researched clay cookstoves have a lifespan of approximately two years (Kishore and Ramana, 2002). Brick by Brick cookstoves were observed to be functional after five years of operation. The variability in lifespan of improved cookstoves can be due to the quality of the sensitization, design, construction, operation, and maintenance of the cookstove.

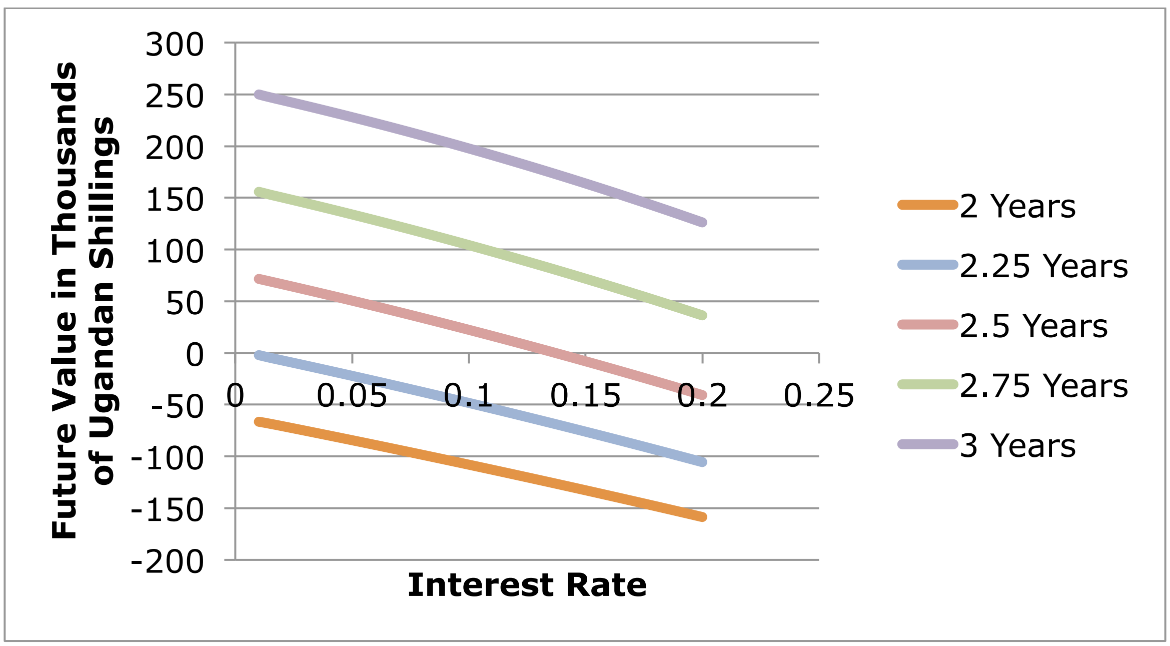

Figure 25: Economic analysis for the *chulli* system for households having Brick by Brick rainwater harvesting systems showing the expected future value in thousands of Ugandan Shillings, variable interest rates, and variable time periods.

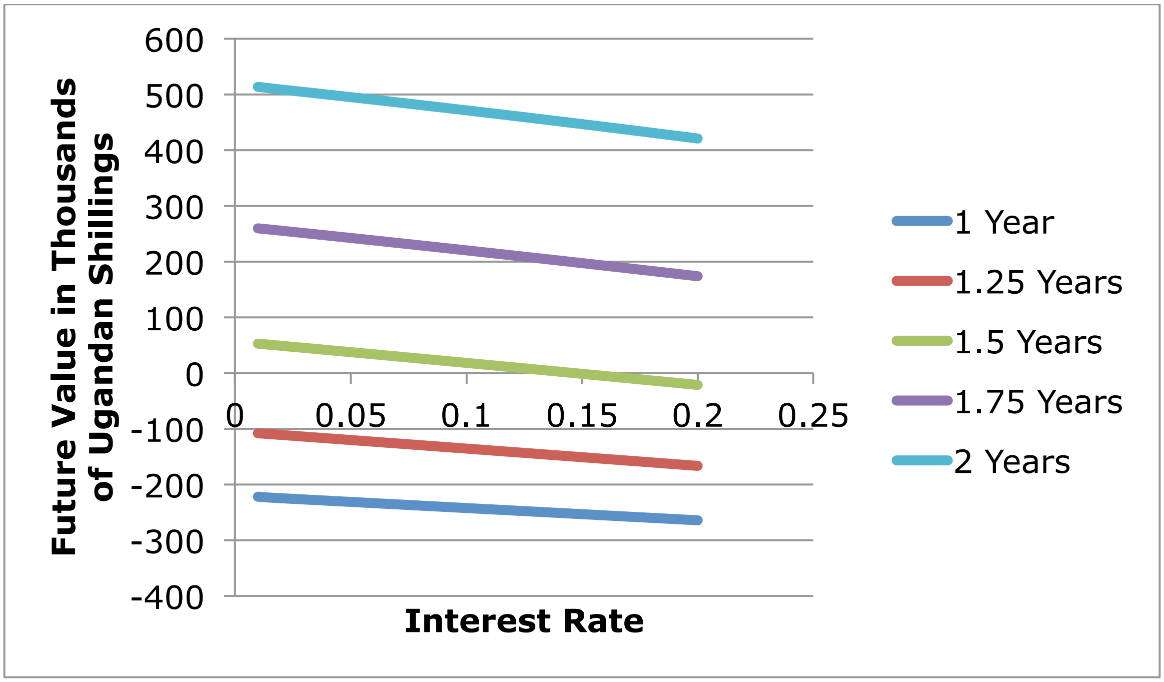

Figure 26: Economic analysis for the *chulli* system for institutions having Brick by Brick rainwater harvesting systems showing the expected future value in thousands of Ugandan Shillings, variable interest rates, and variable time periods.

Figure 25 shows that a positive future value is achieved for a household *chulli* system at an interest rate of 13% or lower after 2.5 or at any interest rate from 1% to 20% after 2.75 years. Figure 26 shows that a positive future value is achieved for an institutional *chulli* system at an interest rate of 14% or lower after 1.5 years or at any interest rate from 1% to 20% after 1.5 years.

Respondents were asked in the survey what their likelihood is of using the *chulli* system. For this question, the participants were shown two photos, Figure 28 and Figure 29, and given a description of the operation. The responses are summarized in Figure 27. As shown twenty-four of the twenty-eight respondents reported either being either “very likely” or “likely” to use the *chulli* system. At the end of the survey, participants had the option to provide any feedback. Participants stated that they were interested in obtaining the *chulli* system and impressed by it and its ability to save time and money and treat water at the same time.

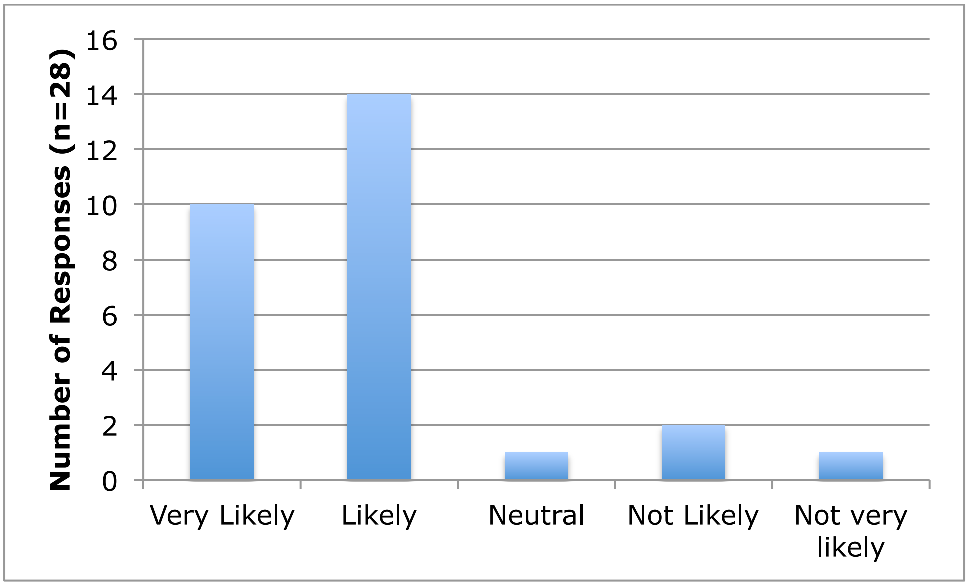

Figure 27: Distribution (n=28) of the responses to question 3.5, "Please see a photo of the proposed water treatment system and listen to an explanation. Based on the photo and the explanation, how likely would you be willing to use this system." in the survey, APPENDIX C for users of Brick by Brick rainwater harvesting tanks in the Rakai District.

4.6.2. Demonstration *Chulli* System

A demonstration water treatment system was built at St. Andrew's Primary School in Rakai District. This school was chosen for multiple reasons: 1) Brick by Brick has a good relationship having implemented many of its programs including the introduction of an eco-san toilet (Trimmer et al., 2016) and a library program, 2) This school does not have a Brick by Brick rainwater harvesting storage tank thus making it not eligible for the raffle that awarded two participants, one household and one institution, a *chulli* system for participating in the survey, 3) The school uses rainwater from rainwater tanks from a company called Crestanks as its primary source of drinking water.

Figure 28 and Figure 29 show photos the of the demonstration *chulli* system constructed for St. Andrew's Primary School in Kalisizo for this thesis. The system operates as follows. Water is placed in the green bucket shown in Figure 21. By opening the tap, water passes through a piping system by gravity until it reaches the coil, where it is heated. The coil is shown at the bottom of Figure 27. The flow rate is adjusted manually until the effluent water is too hot to touch (as recommended by Christen et al., 2009; Islam et al., 2006). The treated water is then collected manually in a household storage container.

Figure 28: Senior Mason Jjunju Charles standing next to the newly completed *chulli* system. Untreated water is placed in the green reservoir (A). Water flows from through the hose into the stove. Water flows through the coil shown in Figure 29, where it is treated. Treated water then flows out of the tap (B). The entry location where firewood is inserted into the stove for cooking is shown (C).

Figure 29: A close-up look inside the stove from Figure 28 highlighting the location of the coiled pipe. After flowing through the hosepipe explained in Figure 28, water passes through this coil where it is heated. After heating in the coil, water flows out of the effluent tap also shown in Figure 28.

After constructing the demonstration system shown in Figure 28 and Figure 29, it was tested for its functionality. The cook who was approximately 5’4” tall was able to operate the system with no difficulty. The thesis author observed a combination of water and steam at the effluent tap, which was also captured on video. The presence of steam implies that the effluent water boiled inside the stove. Water boils at a mean temperature of 100 ºC. A previous study showed a *chulli* with effluent water of approximately 70 ºC. In this study, treated water was tested for thermotolerant coliforms, and none were detected in any of the water samples (Islam et al., 2006). Supporting that these conditions are effective for treating water, approximately 12 seconds is required kill 99.999% of *E. coli*, rotavirus, *Salmonella typhi*, *Vibrio cholerae*, and *Shigella* sp. at a pasteurization temperature of 70 ºC (Ray and Jain, 2011). Given that steam was observed by this study's *chulli* system implying that a temperature of 100 ºC was achieved, that the previous study reported no detection of thermotolerant coliforms in its treated water at 70 ºC, and that approximately 12 seconds is required kill 99.999% of *E. coli*, rotavirus, *Salmonella typhi*, *Vibrio cholerae*, and *Shigella* sp. at a pasteurization temperature of 70 ºC, this information strongly supports that the *chulli* system was able to deliver treated water. In addition to the water treatment, Brick by Brick designs both the ventilation of the cookstove and the kitchen to minimize indoor smoke and air pollution. Compared to a traditional three-stove fire, this system improves the indoor air quality and consequently the public health for the users. Although the *chulli* system functioned successfully, there were a few barriers for implementation. The influent hosepipe detached from the system twice. Brick by Brick tried to repair this using a clamp, but it continued to break. Using a sturdier metallic influent pipe other than plastic could prevent this issue. In addition, the cook was initially unsure how to operate the system to yield the treated water. She was sometimes unsure if it was hot enough to drink. In response, Max Ssenyonga demonstrated how to adjust the tap to adjust the flow rate until the appropriate temperature with the tap being too hot to touch (as suggested and supported by Islam et al., 2006) was reached. Two additional demonstration systems are currently being constructed and modified according to feedback from the system constructed for St. Andrew's Primary School.

4.7. Study Limitations

This had several limitations. First, some data were collected using a survey. Although the survey was designed to minimize the number of flaws and biases, some still expectantly exist. For example, respondents may not have answered some questions truthfully because the answer would imply practices such as not boiling water that the respondent already understands as a health risk. This could be considered a sensitive question (as explained in Jacobsen, 2016). Some respondents may have reported boiling water when they do not actually boil their water. Some respondents may have reported fewer than actual cases of diarrhea from question 2.20 in the survey in APPENDIX C.

The sanitary inspection has its limitations as well. For example, each observation area has a binary response of "yes" or "no" as a potential risk. For example, one of the questions for the sanitary inspection asks if the roof is dirty. Different situations can occur. The roof can be very clean, covered in bird feces, or have a few leaves on it. Weighing the response as opposed to having only two options can help improve the accuracy of the tool's risk score but increase the complexity. Users can use the sanitary inspection as a checklist for maintaining their system in addition to giving themselves a potential risk score.

Lastly, the microbial water quality tests could have been improved. The specific test was chosen due to performance and low cost. However, performing the test multiple times for each sample or increasing the tested sample volume by filtering and diluting the sample, to which the thesis author did not have access during the research activity, would have been advantageous for more accurate concentrations and detections. Ways of improving this could be filtering 100 mL samples before using the plates or using a different test.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

The overall goal of this research is to improve public health, through improved drinking water, directly for communities in the Rakai District in Uganda, and indirectly for other communities in the world by the spread of knowledge. Failure to sustainably manage drinking water can result in many health related issues including diarrheal disease and nervous system damage (WHO, 2011; Jain, 2012; Fry et al., 2013; Prüss-Ustün et al., 2014). This study had three hypotheses each with associated objectives:

[1] Users of Brick by Brick rainwater harvesting tanks in the Rakai District can improve their knowledge of drinking water quality in regards to public health, their sanitation measures, and water treatment methods.

[2] The water quality of the Brick by Brick rainwater harvesting tanks in the Rakai District will not meet the Ugandan drinking microbial water standards.

[3] The suggested treatment technology will be well-received by the community and effectively treat the rainwater.

A survey focusing on drinking water management in regards to public health was developed to assess the knowledge, attitudes, and practices of the users of Brick by Brick rainwater harvesting tanks in the Rakai District (the source population). The results of the survey revealed that twenty of the twenty-eight participants identified contaminated water as a cause of diarrheal disease. The results of the survey also revealed that participants perceived boiling (1), chlorine (2), and filtering (3) as the best three methods of treating water (Objective 1.a). In regards to drinking water treatment practices, the survey showed that the source populations already used boiling (20), filtration (4), chlorination (1), and settling (1) to treat their water (Objective 1.d). A sanitary inspection was also performed for the thirty-three total rainwater harvesting tanks managed by the source population. The average score was 2.27±2.31, which falls between the low and medium expected risk score categories (Objective 1.b and 2.c). The survey also revealed the most common risk areas for the rainwater system were missing broken or dirty concrete floors under tap (19), inadequately drained water collection area (15), and problems with the filer box or first flush system at the tank inlet (11) (Objective 1.c).

Water samples were collected from the thirty-three surveyed Brick by Brick rainwater harvesting tanks in the Rakai District and tests and analyzed for microbial and physic-chemical parameters (Objective 2.a). The most important results for this study come from the 3M™ Petrifilm™ *E. coli*/Coliform Count Plates tests. Fourteen of the thirty-three samples showed detectable levels of colony forming units for coliforms. Two of the thirty-three samples showed detectable levels of colony forming units for *E.*

coli. The samples showing detectable levels of this microbial indicator fail to meet Uganda's national standards: 0 CFU/ 100 mL for both total coliforms and *E. Coli* (UNBS, 2014) (Objective 2.b). Total coliforms and *E. coli* are indicator bacteria that present the likelihood of the presence of fecal contamination. Although samples showed detectable levels of these indicator bacteria, detecting indicator bacteria does not verify that the consumption of this water will pose a health risk. Therefore, the microbial water quality results show that consuming the rainwater may pose a health risk to the users (Objective 2.c).

A demonstration *chulli* system that sustainably treats water using excess heat from a cooking stove to disinfect water through a coiled pipe embedded in the cooking stove was constructed for St. Andrew's Primary School in Rakai District and provided for the staff to use (Objectives 3.a & 3.b). The thesis author observed a combination of water and steam at the effluent tap during this system's operation, supporting that the system was able to effectively treat the water (Objective 3.c). Given the performance of the system and the microbial water quality results, this system demonstrates the potential for the system to treat raw rainwater that may be contaminated with microbial water constituents (Objective 3.d). The cook and staff at St. Andrew's stated that the system impressed them and saved them time spent boiling water and collecting fuel for consumption (Objective 3.e). Although survey participants and users of this system found this technology to be different than their known methods of treating water, they demonstrated positive feelings by its capabilities after explanation. In order to promote the widespread use of this technology, the operation would need to be clearly explained to potential users (Objective 3.f).

In addition to all of the results outlined in this study, it is important to mention that unmeasured impacts are possible as a result of this study. For example, surveying participants about drinking water quality and public health could serve as a reminder to effectively manage their drinking water. In addition, a student planning on attending a university, who was at one of the participating during the study, mentioned that he was interested in *chulli* system and promoting its use.

Based on the results of this study. It is recommended that the users of the Brick by Brick rainwater harvesting tanks continue to maintain their rainwater harvesting tanks according to the sanitary inspections in APPENDIX D and treat their water before consumption. The *chulli* system is a sustainable means of treating water because it effectively treats the water, saves the users time and money, and has low environmental impact due to the reduced fuel consumption. This research demonstrates that the *chulli* system is sustainable from environmental, economic, and social standpoints. In order to promote the expansion of this project, different measures are recommended. An educational program can be developed in order to further demonstrate the usefulness of the *chulli* system to potential users. The educational program would include the economic and health benefits to demonstrate the system's value to the user. From the economic analysis, the *chulli* system can save households 13,188 UGX monthly and have a positive future value after 2.5 years; it can save institutions 61,500 UGX monthly and have positive future value after 1.5 years. In addition, Brick by Brick designs its cookstoves to minimize the indoor air pollution and consequently improve indoor air quality and public health compared to traditional three-stone fires. Due to the systematic setup of schools, these institutions would be appropriate target for the introduction of this system. In regards to households, the female heads of the households primarily responsible for cooking and managing the water would be useful stakeholders to help promote the widespread use of this technology. Demonstrating the correct use and benefits of this system would help them understand the potential value for adopting the technology.

Many opportunities for further research are available based on this study. More in depth microbial water quality tests can be performed on rainwater for specific pathogens. The treated water can also be tested for chemical parameters. For the *chulli* system, researchers can measure the reduced environmental impact using the system. It would also be useful to test the system for chemical parameters that can occur from leaching from the coiled pipe. Lastly, developing and introducing a program that provides more *chulli* systems can provide better monitoring data, which can guide the introduction of this system on a larger scale.

This study focused on the goal of improving public health through assessing and bettering drinking water management and practices. Through learning about sustainable water management and treatment methods, the thesis author was able to sustainably manage his water and introduce new methods to the sample population. Given the results of this study, the thesis author does believe that the goal was achieved. At the same time, technology is always continuing to change and improve, so progress will inform even better approaches to safely managing water.

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APPENDIX A: UNIVERSITY OF SOUTH FLORIDA RESEARCH EXEMPTION

Here is the letter stating the exemption from the University of South Florida’s Internal Review Board.

USF
UNIVERSITY OF SOUTH FLORIDA

RESEARCH INTEGRITY AND COMPLIANCE
Institutional Review Boards, FWA No. 00001669
12901 Bruce B. Downs Blvd., MDC035 • Tampa, FL 33612-4799
(813) 974-5638 • FAX (813) 974-7091

3/1/2017

James Murduca
[redacted]

RE: **Not Human Subjects Research Determination**
IRB#: **Pro00028555**
Title: Assessment of Drinking Water Quality Management and Treatment Feasibility

Dear James Murduca:

The Institutional Review Board (IRB) has reviewed your application and determined the activities described in the application are designed to establish the need for and creation of a water treatment system. The activities are not designed to contribute to generalizable scientific knowledge. Therefore, this project is not under the purview of the USF IRB and approval is not required. If the scope of your project changes in the future, please contact the IRB for further guidance.

All research activities, regardless of the level of IRB oversight, must be conducted in a manner that is consistent with the ethical principles of your profession. Please note that there may be requirements under the HIPAA Privacy Rule that apply to the information/data you will utilize. For further information, please contact a HIPAA Program administrator at 813-974-5638.

We appreciate your dedication to the ethical conduct of research at the University of South Florida. If you have any questions regarding this matter, please call 813-974-5638.

Sincerely,

[redacted]

John Schinka, Ph.D., Chairperson
USF Institutional Review Board

APPENDIX B: INTERNATIONAL HEALTH SCIENCES UNIVERSITY RESEARCH APPROVAL

Here is the letter stating the approval from the Research Ethics Committee at the International Health Sciences University.

IHSU INTERNATIONAL HEALTH SCIENCES UNIVERSITY sanitas per scientiam

making a difference to health care

Research Ethics Committee

UG-REC-015

20th April, 2017

IHSU-REC/0044

Mr. James Murduca
Principal Investigator
C/o Male Alice
Co-Principal Investigator
P.O Box 972
Masaka, Uganda

IHSU INTERNATIONAL HEALTH SCIENCES UNIVERSITY sanitas per scientiam
20 APR 2018
APPROVED / VALID UNTIL
RESEARCH ETHICS COMMITTEE
P.O. Box 7782, Kampala - Uganda

Category of review

- [x] Initial review
- [ ] Continuing review
- [ ] Amendment
- [ ] Reactivation
- [ ] SAEs

RE: "ASSESSMENT OF DRINKING WATER QUALITY MANAGEMENT AND A TREATMENT FEASIBILITY STUDY FOR BRICK BY BRICK WATER TANKS IN RAKAI"

Reference is made to the above mentioned protocol which was submitted to the International Health Sciences University Research Ethics Committee (IHSUREC) for initial review and approval.

You have addressed all the issues earlier raised, and the committee is satisfied with the responses submitted in version 2.0 dated 20th April, 2017.

I am glad to inform you that your study has been approved for a period of one year from 20th April, 2017 to 20th April, 2018.

The documents approved include the following;

Document	Language	Version	Submission date
Protocol	English	Version 2.0	18th April, 2017
Informed consent			
Informed consent	English	Version 2.0	18th April, 2017
Informed consent	Luganda	Version 2.0	18th April, 2017
Data collection forms			
Semi-Structured Questionnaire	English	Version 2.0	18th April, 2017

The International Health Sciences University
P.O. Box 7782 Kampala – Uganda
(+256) 0312 307400 email: info@ihsu.ac.ug
web: www.ihsu.ac.ug

Please note that any problem of a serious nature as a result of this study to the participants should be reported to IHSU-REC and Uganda National Council of Science and Technology (UNCST) immediately.

Also note that annual report and request for renewal where applicable should be submitted at least one month before the expiry date of approval. In addition, you are also required to submit copies of the stamped approved documents to the Uganda National Council for Science and Technology (UNCST) before the study can commence.

We would like to congratulate you and wish you a successful conduct of the study.

Yours Sincerely,

INTERNATIONAL HEALTH SCIENCES UNIVERSITY
20 APR 2018
APPROVED / VALID UNTIL
RESEARCH ETHICS COMMITTEE
P. O. Box 7782, Kampala - Uganda

20 APR 2017

Dr. Samuel Kabwigu
IHSU-REC Chairperson

Date

The International Health Sciences University
P.O. Box 7782 Kampala – Uganda
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APPENDIX C: RESEARCH SURVEY

Here is the survey used to collect the reported data from the research participants.

Section 1: Demographics

This will ask about general information about your rainwater harvesting tanks and the community, which the tank serves. The respondent should be the primary adult of eighteen years or older responsible for managing your family/community's water.

1.1 How many rainwater harvesting tanks does your family/community have? ______________________________

1.2 What is the capacity of each tank (only include tanks that are of 1000 L or greater)?

Tank #____ Capacity_______ Tank #____ Capacity_______

Tank #____ Capacity_______ Tank #____ Capacity_______

Tank #____ Capacity_______ Tank #____ Capacity_______

(If there are more than six tanks, please include them)

1.3 Which of these tanks are Brick by Brick Construction Rainwater Harvesting Tanks? ______________________________

1.4 Which of these tanks are not Brick by Brick Construction Rainwater Harvesting Tanks? ______________________________

1.5 How many people in your community are served currently by the rainwater tank, and what are their ages?

_________# of users ages 0-5

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__________# of users ages 6-10

__________# of users ages 11-15

__________# of users ages 16-20

__________# of users ages 21-30

__________# of users ages 31-40

__________# of users ages 41-50

__________# of users ages 51-60

__________# of users ages 61 or greater

Section 2: Practices

This will show the practices of the users of the tank.

2.1 What is your primary drinking water source?

- Piped Water
- Bottled Water
- Rainwater
- Groundwater
- Surface Water
- Spring
- Other (please specify)

____

____

____

2.2 What is your secondary drinking water source?

- Piped Water
- Bottled Water
- Rainwater
- Groundwater
- Surface Water
- Spring
- Other (please specify)

____

____

____

2.3 Do you drink the water from your rainwater harvesting tank?

- Yes
- No

2.4 Do you treat your water before drinking?

- Yes
- No

2.5 If you treat your water, how do you treat it?

________Chlorine ________Settling

________Distillation ________Solar Disinfection

________Boiling ________Coagulation

________Filtering ________Flocculation

________Other (Please Specify) ________________________________

2.6 If you do not treat your water, why do you not treat it (check all that apply)?

- ☐ Too expensive
- ☐ Too much time
- ☐ Ineffective
- ☐ Water is already clean
- ☐ Other (please specify)

____

____

____

2.7 If you boil your water, for what duration of time do you boil you water per day?

___________ minutes

2.8 If you boil your water, what kind of fuel do you use to boil your water?

- ○ Charcoal
- ○ Solar Electricity
- ○ Central Grid Electricity
- ○ Gas
- ○ Firewood
- ○ Other (please specify)

____

____

2.9 If you boil your water, how much fuel do you use to boil your water?

______________ (type of fuel) _____________ (units)

2.10 Does livestock pass on the dirt road next to the catchment area?

- ○ Yes
- ○ No

2.11 Does someone cook for your community?

- ○ Yes
- ○ No

2.12 Does the community being served by the tank have a kitchen?

- ○ Yes
- ○ No

2.13 Does this community have a stove?

- ○ Yes
- ○ No

2.14 How many stoves does this community own?

____

2.15 If you have a stove, what kind of stove do you use?

- ○ Three-stone fire
- ○ Electric Stove
- ○ Gas Stove
- ○ Fuel-efficient stove
- ○ Charcoal Stove
- ○ Other (please specify)

______________________________ ______________________________

2.16 How much money per month do you spend on fuel?

___________ UGX

2.17 For what duration of time do you cook per day?

___________ minutes

2.18 Are children under five years being served drinking water by the rainwater harvesting tank?

- ○ Yes
- ○ No

2.19 How many liters of water is each person drinking per day?

_________ Liters

2.20 How often does diarrheal illness occur for the average member of your community?

_________ times per person per year

Comment:

____

____

____

2.21 How do you store your drinking water?

____

____

____

2.22 For how long is your drinking water stored?

_________ days

Section 3: Attitude and Knowledge

This will talk about the respondent's attitude and knowledge towards drinking water quality and health.

3.1 What are the possible causes of diarrhea? (check all that apply)

- ☐ Contaminated Food
- ☐ Contaminated Water
- ☐ Microbial Pathogens
- ☐ Lack of Hand Washing
- ☐ Other (please specify) ______________________________
  ____
  ____

3.2 For people of what age range is diarrheal disease most harmful (check all that apply)?

- ☐ ages 0-5
- ☐ ages 6-10
- ☐ ages 11-15
- ☐ ages 16-20
- ☐ ages 21-30
- ☐ ages 31-40
- ☐ ages 41-50
- ☐ ages 51-60
- ☐ ages 61 or greater

3.3 Please rank from the available choices the top three ways of treating water (1 = best way of treating water, 2 = second best way of treating water, 3 = third best way of treating water).

________Chlorine

________Distillation

________Boiling

________Filtering

________Settling

________Solar Disinfection

________Coagulation

________Flocculation

________Other #1 (Please Specify) ________________________________

________Other #2 (Please Specify) ________________________________

________Other #3 (Please Specify) ________________________________

3.4 How does rainwater become contaminated (check all that apply)?

- ☐ Air pollution
- ☐ unclean roofs
- ☐ unclean gutters
- ☐ unclean tap
- ☐ open inlet
- ☐ unclean utensils
- ☐ Other (please specify)

____

____

____

3.5 Please see a photo of the proposed water treatment system and listen to an explanation. Based on the photo and the explanation, how likely would you be willing to use this system?

- ○ Very likely
- ○ Likely
- ○ Neutral
- ○ Not likely
- ○ Not very likely

3.6 Overall, on a scale of 1 to 5 (5 being the most satisfied) how satisfied are you with your Brick by Brick rainwater harvesting tank?

- Very satisfied (5)
- Satisfied (4)
- Neutral (3)
- Unsatisfied (2)
- Very unsatisfied (1)

Would you like to provide any further comments on this topic or survey?

____

____

____

____

____

____

____

____

____

Thank you so much for taking the time to complete this survey!

APPENDIX D: SANITARY INSPECTION

Here is the sanitary inspection used to collect the data to determine the likely routes of contamination and estimate the risk for the rainwater harvesting systems.

Sanitary Inspection Form: Rainwater Harvesting Tank

Part 1. General information:

a. Tank location: ....

b. Village/Town: ....

c. People served: ....

d. Water sample taken? .... Sample ID ....

e. Date of visit: ....

Part 2. Risk assessment: Circle the most appropriate answer. A 'Yes' answer means that there is a potential risk and a 'No' answer that there is no or very low risk. See explanation on reverse.

	Observation
1. Are there visible signs of contamination on the roof (e.g., feces, dirt, leaves)?	Y/N
2. Is the gutter system that collects rainwater dirty or blocked?	Y/N
3. Are there any problems with the filter box or first flush system at the tank inlet?	Y/N
4. Is there any other point of entry to the tank that is not properly covered?	Y/N
5. Is the top or wall of the tank cracked or damaged?	Y/N
6. Is the tap leaking or broken?	Y/N
7. Is the concrete floor under the tap missing, broken or dirty?	Y/N
8. Is the water collection area inadequately drained?	Y/N
9. Is there any source of contamination around the tank or water collection area?	Y/N
10. Is a bucket in use and left in a place where it may become contaminated?	Y/N
Risk of contamination (add the number of 'Yes' answers:	....../10

Part 3. Results and comments:

a. Risk of contamination (check appropriate box):

9-10 = Very high	6-8 = High	3-5 = Medium	0-2 = Low

b. The following risks were observed:

Part 4. Name and signature of inspectors:

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Explanatory Notes: Rainwater Harvesting Tank

1. Are there visible signs of contamination on the roof (e.g. feces, dirt, leaves)? Water quality is at risk if the roof is dirty or contaminated.

2. Is the gutter system that collects rainwater dirty or blocked? Dirty gutters can contaminate the rainwater or introduce dirt into the tank in the same way the roof can.

3. Are there any problems with the filter box or first flush system at the tank inlet? Rainwater harvesting tanks should have a way to divert the first water collected during a rainstorm.
The first flow (especially at the end of the dry season) may contain vegetation, dirt, and animal feces washed from the roof, which are a risk to water quality.

4. Is there any other point of entry to the tank that is not properly covered? Open rainwater collection tanks collect dust and dirt from the air, which is a possible risk to water quality. They can also be mosquito breeding sites, and the mosquitoes may spread dengue fever and malaria, which is a health risk (though not a water quality risk).

5. Is the top or wall of the tank cracked or damaged? Deep cracks can allow contaminants to reach the rainwater stored in the tank.

6. Is the tap leaking or broken? A broken tap can become a pathway for contaminants. You will need to check that any water around the tap is from a leak rather than from being spilled.

7. Is the concrete floor under the tap missing, broken or dirty? Missing or broken drainage under the tap can lead to pools of water collecting which pose a risk.

8. Is the water collection area inadequately drained? If water does not drain away from the collection area, then water (possibly contaminated) could backflow into the water source or the soil can erode away and cause damage to the tank.

9. Is there any source of contamination around the tank or water collection area? Feces, garbage and other waste are a risk to the water quality.

10. Is a bucket in use and left in a place where it may become contaminated? Buckets, cups or other devices used to collect water need to be properly stored and kept clean so that safe drinking water does become contaminated.

Sanitary Inspection Form adapted from:

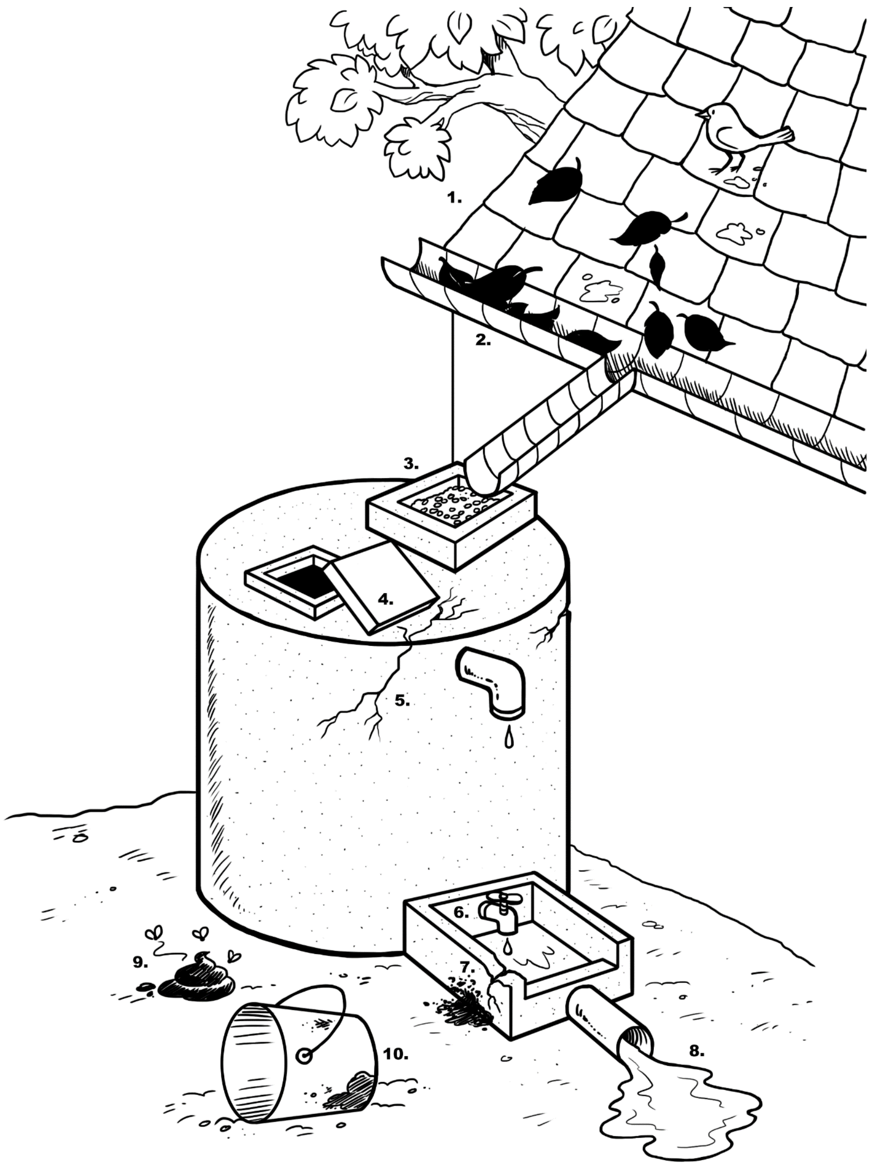
World Health Organization (2012). Rapid Assessment of Drinking-Water Quality: A Handbook for Implementation. WHO, Geneva, Switzerland. Available at: www.who.int/water_sanitation_health/publications/2012/rapid_assessment/en/index.html

World Health Organization (2005). Water Safety Plans: Managing Drinking-Water Quality from Catchment to Consumer. WHO, Geneva Switzerland. Available at: www.who.int/water_sanitation_health/dwq/wsp0506/en/index.html

World Health Organization (1997). Guidelines for Drinking Water Quality, Second Edition, Volume 3, Surveillance and Control of Community Supplies. WHO, Geneva, Switzerland. Available at:
www.who.int/water_sanitation_health/dwq/gdwq2v1/en/index2.html

CAWST

Illustration of a Rainwater Harvesting Tank



APPENDIX E: CONSENT FORMS

This is the English consent form used to conduct the research.

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Informed Consent to Participate in Research Involving Minimal Risk and Authorization to Collect, Use and Share Your Health Information

Pro # _____00028555_____

You are being asked to take part in a research study. Research studies include only people who choose to take part. This document is called an informed consent form. Please read this information carefully and take your time making your decision. Ask the researcher or study staff to discuss this consent form with you, please ask him/her to explain any words or information you do not clearly understand. The nature of the study, risks, inconveniences, discomforts, and other important information about the study are listed below.

We are asking you to take part in a research study called:

Assessment of Drinking Water Quality Management and Treatment Feasibility

The person who is in charge of this research study is James Murduca. This person is called the Principal Investigator. However, other research staff may be involved and can act on behalf of the person in charge. He is being guided in this research by Dr. Jim Mihelcic and Brick by Brick's Program Director Alice Male.

The research will be conducted in the Rakai District at the communities that are being served by Brick by Brick rainwater harvesting tanks.

This research is being sponsored by Brick by Brick.

Purpose of the study

The purpose of the study is to understand the management practices of users of the tanks and suggest improvements should there be a need.

Why are you being asked to take part?

We are asking you to take part in this research study because you are a user of Brick by Brick's rainwater harvesting tanks.[

Study Procedures:

If you take part in this study, you will be asked to:

- Take part in a one-time fifteen minute interview that will ask questions about your knowledge of drinking water quality and health and your rainwater harvesting tank management practices.

- Allow the principal investigator to perform a thirty-minute sanitary inspection approved by the World Health Organization.
- Allow the researcher to collect water samples from your rainwater harvesting tank. These samples will be tested, and the results will be presented to you upon your request.

After the data are collected, the data will be transferred to an Excel file that is locked with a password. The only identifier that will connect your data to your personal information will be two-letter representation of your survey. This code will identify the respondent in another Excel file. The purpose of keeping this code is, so that the respondent can be entered into the raffle for the treatment technology. This study will not share your data with your employer.

Total Number of Participants

About 30 individuals will take part in this study in the Rakai District.

Alternatives / Voluntary Participation / Withdrawal

You do not have to participate in this research study.

You should only take part in this study if you want to volunteer. You should not feel that there is any pressure to take part in the study. You are free to participate in this research or withdraw at any time. There will be no penalty or loss of benefits you are entitled to receive if you stop taking part in this study.

Benefits

The potential benefits of participating in this research study include:

- An assessment for improving your drinking water management if applicable.
- A voluntary opportunity to participate in a raffle for a prize of a sustainable drinking water treatment technology

Risks or Discomfort

This research is considered to be minimal risk. That means that the risks associated with this study are the same as what you face every day. There are no known additional risks to those who take part in this study.

Compensation

There will be no compensation provided for the participants in the study; however, participants will regain knowledge in drinking water quality and management and have the voluntary opportunity to participate in a raffle for a price of a sustainable drinking water treatment technology.

Costs

It will not cost you anything to take part in the study.

Privacy and Confidentiality

We will keep your study records private and confidential. Certain people may need to see your study records. Anyone who looks at your records must keep them confidential. These individuals include:

- The research team, including the Principal Investigator, study coordinator, and all other research staff.
- The USF Institutional Review Board (IRB) and related staff who have oversight responsibilities for this study, including staff in USF Research Integrity and Compliance.
- The sponsors of this study and contract research organization.

We may publish what we learn from this study. If we do, we will not include your name. We will not publish anything that would let people know who you are.

You can get the answers to your questions, concerns, or complaints

If you have any questions, concerns or complaints about this study, or experience an unanticipated problem, call James Murduca at +256791995788 or email james.murduca@gmail.com.

If you have questions about your rights as a participant in this study, or have complaints, concerns or issues you want to discuss with someone outside the research, call the USF IRB at (813) 974-5638 or contact by email at RSCH-IRB@usf.edu. You can also contact the chairperson of the International Health Science University – Research Ethics Committee, Dr. Samuel Kabwigu, at 0779610100 or the Uganda National Council for Science and Technology contact person, Dr. Julius Ecuru at 0414705500.

Consent to Take Part in this Research Study

I freely give my consent to take part in this stud. I understand that by signing this form I am agreeing to take part in research. I have received a copy of this form to take with me.

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____________________________________ __________

Signature of Person Taking Part in Study Date

____

Printed Name of Person Taking Part in Study

Should the participant opt to partake in this study and provide a thumbprint alongside a witness instead of the participant signing his or her name, he or she may do so here.

____________________________________ __________

Thumbprint of Person Taking Part in Study Date

____________________________________ __________

Signature of Witness to Person Taking Part in Study Date

____

Printed Name of Witness to Person Taking Part in Study

Statement of Person Obtaining Informed Consent

I have carefully explained to the person taking part in the study what he or she can expect from their participation. I confirm that this research subject speaks the language that was used to explain this research and is receiving an informed consent form in their primary language. This research subject has provided legally effective informed consent.

Signature of Person obtaining Informed Consent Date

Printed Name of Person Obtaining Informed Consent

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This is the Luganda consent form used to conduct the research.

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P. O. Box 7782, Kampala - Uganda

Okukiriza okwetaba mukunonyereza okutalinamu buzibu bwona n'okusaba olukusa okukungaanya, okweyambisa n'okugabana nabalala ebyo byomanyi kubyobulamu

Pro # _____00028555_____

Osabibwa okwetaba mukunonyereza kuno era tolina kukabibwa muntu yenna. Ekiwandiiko kino olina kukyijuzaamu nga omaze kukikiriza. Osabiddwa okusoma ebiwandikiddwa nobwegendereza era wewe obudde obulungi olyooke okole okusalawo. Buuza omunonyereza akunyonyole bulungi buli ekiri mukiwandiiko kino. Ebikwaata kukunonyereza kuno, ebizibu byona ebirimu n'ebintu byonna oby'omugaso binyonyoddwa bulungi wammanga.

Tukusaba okwetaba mukunonyereza kuno okuyitibwa:

Engeri yokutumbula omutindo gw'amazzi gwoonnywa n'okugalongoosa bwekiba kyetagisa

Avunanyizibwa kukunonyereza kuno ye James Murduca era omuntu ono yemunonyereza omukulu newankubadde bakola nabo basobola okwetaba mukunonyereza kuno kululwe. Omunonyeraza omukulu alungamizibwa era awabulwa Dr. Jim Mihelcic wama n'akulira pulogulaamu za Brick by Brick omukyala Alice Male.

Okunonyera kuno kugenda kukolebwa mubitundu bye Rakai ewali taanka za Brick by Brick.

Okunyoreza kuno kuwagiddwa Brick by Brick.

Omugaso gw'okunonyereza

Omugaso g'okunonyereza kwekutegeera enkozesa ya taanka nokongerako omutindo bwekiba kyetagisiza.

Lwaki obuziibwa okwetaba mukunonyereza kuno

Tukusaba okwetaba mukunonyereza kuno kubanga gwe akozesa taanka za Brick by Brick.

Emitendera

Bwewetaba mukunonyereza kuno, ojakusabibwa:

- Okwetaba mu interview yadakiika kuminataano nga erimu ebibuuzo ebikwaata kukumanya kumutindo gwamazzi goonywa nenkozesa ya taanka

- Okukiriza omunonyereza omukulu okulambula ebyobuyonjo okumala edakiika assaatu nga bwekyakakasibwa ekitongole ekyobulamu munsi yonna (WHO)
- Okukiriza omunonyereza okukungaanya amatondo g'amazzi okuva ku taanka yo. Amatondo gano gajja kukebererwa era ebinavaamu bijakuweebwa bwonaaba obisabye.

Bwetunamala okukungaanya obubaka bujja kuterekebwa mu excel file bugalirweemu ne number eyekyaama.Ekintu kyoka ekisobola okutuusa kububaka bwewatuwa zijja kuba ennukuta bbiri eziri mu kiwandiiko kyetwakubulizaamu. Ennamba eyekyaama eno ejakwawula eyaddamu ekibuuzo mu Excel file. Omugaso ogw'okuuma ennamba ey'ekyaama guli nti eyaddamu ebibuuzo ayingira mukazannyo akanalongoosa amazzi ne tekinologiya omujja. Akukozesa kumulimo tajjakulaba wadde byozeemu mukunonyereza kuno.

Abanetaba mu kunonyereza

Abantu abali eyo mumakumi assatu bebagenda okwetaba mukunonyereza kuno mu disitulikiti ye rakai.

Obyokusalawo okwetaba mukunonyereza oba okuvaamu mubyokunonyereza

Sikyateeka okwetaba mukunonyereza kuno

Olina okwetabamu bwooba oyagadde okutuyambako. Olina kwetabamu nga tolina akusindikiriza wadde. Oliwaddembe okwetabamu oba okuvaamu obudde bwonna. Tewali kiyinza kutuukako wadde kyofiirwa bwolekeraawo okwetaba mukunonyereza kuno.

Byofunamu

Byofuna nga wetabye mukwetaba mukunonyereza mulimu bino wammanga:

- Tujakulaba engeri yokutumbula omutindo gw'amazzi gwoonnywa bwekiba kyetagisa
- Okwetaba mukajazannyo era owangule akakwaata kukulongoosa amazzi ogwokunnywa

Ebizibu oba okutataganyizibwa

Okunonyereza kuno kukoleddwa nga tekulina bulabe bwonna. Kino kitegeeza nti obuzibu obutonotono obuyinza okusanngwaamu bweebo bwetusanga mubulamu obwabulijjo. Tewali buzibu bulala bw'oyinza kusanga mukunonyereza kuno.

Okuliyirirwa

Tewajakubaawo kuliyirira muntu yenna anetaba mukunonyereza kuno newankubadde abanetabamu bonna bagenda kufuna obukugu mukumanya amazzi amalungi n'omutindo gwaago wamu n'ogakuuma era bajakufuna omukisa okwetaba mukazannyo akalimu okuwangula ngakakwaata kutekinoligiya akuuma amazzi ag'okunnywa ag'omutindo.

Kigula kyenkanaki

Tewali kyotekeddwa kussasula okwetaba mukunonyereza kuno.

Okukuuma by'otugambye

Tujakukuuma obubaka bwona bwonaaba otuwadde nga bwakyaama nnyo. Abantu abamu bayinza okwetaaga okulabako ku ebyo byetunaaba tukunganyiiza okuva mugwe naye buli abitunulako alina okubikuuma nga byakyaama nnyo. Abantu abayinza okubitunalako mulimu bano wammanga:

- Ekibinja y'abanonyereza okuli omunonyereza omukulu, akwasagannya ebyokusoma nabalala abali kulukiiko olunonyereza.
- USF Institutional Review Board (IRB) nabakozi abali kakakiiko ako abalina obuvunanyiizibwa obwokuntinko mukunonyereza kuno nga otwaliddemu USF Research Intergrity and Compliance.
- Abatadde ssente mukunonyereza kuno wamu naba Brick by Brick mu program yabwe eyamazzi amayonjo era ag'omutindo.

Tuyinza okufulumya byetubayiga mukunonyereza kwaffe mu mawulire. Bwetunaaba tukikoze, errinya lyo tetujja kulitekaamu. Tetujja kufulumya kintu kyonna kiyinza kumanyisa bantu balala bikwataako.

Osobola okufuna okudibwaamu ebibuuzo, okwemulugunnya oba okuwabula

Bwooba olina ebibuuzo, okwemulugunnya kwonna okukwaata kukunonyereza kuno oba nga ofunyeemu obuzibu bonna, kubira James Murduca ku number y'essimu +256791995788 oba owereze obubaka obuwandiike kumukutu guno james.murduca@gmail.com.

Bwooba olina ebibuuzo ebikwaata ku ddembe lyo nga anetaba mukunonyereza oba nga olina okwemulugunnya oba okuwabula konna oba nga oyagala okubagannya ebirowoozo kubikwata kukunonyereza kuno, kubira USF IRB kussimu (813)974-5638 oba bawandikire obubaka nga weyambisa emeyiro eno RSCH-IRB@usf.edu. Osobola okukubira ssentebe wa International Health Science University – Research Ethics Committee, Dr. Samuel Kabwigu ku nnamba y'essimu eno 0779610100 oba okukubira atukibwaako ku Uganda National Council for Science and Technology Dr. Julius Ecuru ku nnamba y'essimu eno 0414705500.

Okukiriza okwetaba mukunonyereza kuno

Nzikiriza nga tewali ankase okwetaba mukunonyereza kuno. Nkitegeera nti bwenzisa omukono kukiwandiiko kino mba nzikiriza okwetaba mukunonyereza kuno. Nfunye kopi y'ekiwandiiko kino era ngenze nayo.

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________________________________ ________________

Omukono gw'eyetabye mukunonyereza Ennaku z'omwezi

____

Errinya lyooyo eyetabye mukunonyereza

Singa eyatabye mukunonyereza kuno ayagala kuteekako kinkumu nga waliwo amusemba okusinga okuwandiika oba okusaako omukono akirizibwa era akikolera wano wammanga;

....

Ekinkumu kyoyo eyatebye mukunonyereza

....

Omukono gooyo amusemba

....
Erinnya lyooyo assemba eyatabye mukunonyereza

Obweyamu bw'oyo abuuza obantu okwetaba mukunonyereza kuno

Nyinyonyodde n'obwegendereza omuntu agenda okwetaba mukunonyereza byasubira nga yetabyemu. Nkakasa nti eyetabyeemu ayogera lulimi oluzalirwanwa era akiriza okwetaba mukunonyereza nga afuna ekiwandiiko mululimi oluzalirwanwa. Eyatabyeemu akiriza bino byonna mumateeka.

Omukono gw'abuuza

Ennaku z'omwezi

Errinya ly'oyo abuuza

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APPENDIX F: COPYRIGHT PERMISSIONS

F.1 Central Intelligence Agency Copyright Notice

The Copyright Notice below is for the use of material in Figure 3.

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Centre for Affordable Water and Sanitation Technology

424 Aviation Road NE
Calgary, Alberta, T2E 8H6, Canada
Phone: + 1 (403) 243-3285, Fax: + 1 (403) 243-6199
E-mail: resources@cawst.org, Website: www.cawst.org

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The email correspondence below is for the use of material in Figure 8 and Figure 9.

Gmail James Murduca <james.murduca@gmail.com>

[ITHAKA Support] Request #75788: Request for Permission to Use a Figure from an Article

1 message

JSTOR Support <support@jstor.org> Tue, Feb 13, 2018 at 4:46 PM
Reply-To: JSTOR Support <support@jstor.org>
To: James Murduca <james.murduca@gmail.com>

##- Please type your reply above this line -##

Your request (75788) has been updated. To add additional comments, reply to this email.

Farraz Daudi (ITHAKA Support)
Feb 13, 16:46 EST

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Please let me know if you have any additional questions.

Sincerely,

Farraz

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Website Support Specialist, User Services
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James Murduca
Feb 13, 02:05 EST

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I look forward to hearing back.

Best,

James Murduca

Attachment(s)
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ABOUT THE AUTHOR

James Murduca completed his Bachelor of Science degree in Mechanical Engineering at The College of New Jersey in 2013. Realizing his affinity for fluid mechanics, appreciation of water resources, and passion for community service, he decided to pursue his Master of Science in Civil Engineering at the University of South Florida in the Master's International program. During this program, he completed a two-year internship service program with Brick by Brick in Masaka, Uganda. His time spent here has taught him to be a more responsible global citizen. Shortly after his return from Uganda, James started working with Amec Foster Wheeler in Lakeland, Florida, as a civil engineer. James has a huge passion for ethics, philosophy, music, fitness, nutrition, and spending time with his family, friends, and dog, Simba.