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ChangeALife Uganda: Migyera Community Water Project

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Executive Summary

In many parts of the developing world, poor water quality and water scarcity affect human health and their economic and social well-being. Although much progress has been made towards increasing access to improved water supplies on a global level, there is a significant disparity between those living in urban and rural settings (UNICEF and WHO 2014). Following this trend, in the country of Uganda 85% of the total population of 34 million lives in rural areas. Of those rural Ugandan households, 70% have access to an improved water supply (UNICEF and WHO 2014).

Partnering with ChangeALife Uganda (CALU), a local Ugandan non-profit organization, this project evaluates the water supply in the rural village of Migyera while taking into account the multitude of compounding factors, such as seasonal fluctuations in rainfall and diversity of water sources. CALU's interest in water stems from its mission to provide education and health care, improving the livelihoods of children who are the most susceptible to water borne illnesses.

The project seeks to evaluate current, local perceptions of quality, access, distribution, and use of water resources in Migyera Town Council, Uganda in order to provide recommendations to the client. Primary research comprised of three key data collection areas 1) household surveys, 2) water quality testing, and 3) geospatial analysis, was used to examine overarching questions on water management and sanitation and health of the community. This project provides recommendations to the client on these questions, including educational measures, water treatment and storage strategies, and an overview of the influence of groundwater chemical concentration on long-term health.

The first section of the report introduces the project site with a discussion of the importance of access to clean water to community health and livelihoods. Our site, located 140 kilometers north of Kampala, Uganda's capital, is the Migyera Town Council. Located in Central Uganda, nicknamed the "Cattle Corridor", the villages that comprise the Migyera Town Council are rural communities and like a majority of the country's rural population, rely heavily on groundwater. Over time, the unique qualities of the regional environment, the bimodal annual precipitation cycle, and the unique bedrock that covers 90 percent of the country, including our study area, have contributed to the creation of this fractured aquifer system. These fractured aquifers provide one of the major sources of potable drinking water in the area; however, their complex structures also contribute to an already challenging resource management situation.

The second section of the report details the methods used, both in the field and at Duke University. The specifics about the project's data collection techniques included are the creation and implementation of the survey, collection and processing of bacteriological and chemical water samples, and compiling geospatial data.

The third and fourth sections of the thesis consist of the analysis, results, and recommendations based on our three driving questions.

(1) What are all the accessible water sources in Migyera Town Council and what are their contamination levels?

Groundwater sampling of 10 local boreholes found arsenic levels (0.0257 ppm) that exceeded the WHO and Uganda drinking water standards (0.01 ppm). Fluoride, the other main constituent of concern, was detected at levels above the WHO (1.5 ppm) and Ugandan (1 ppm) drinking water quality standards in one borehole (3.309 ppm).

Bacterial contamination was found to be an issue in the household water samples. Total fecal coliform counts exceeded the WHO standard of 0 per 100ml for 87% of the study households. Some households have concentrations of up to 10,000 fecal coliform units per 100ml of water.

(2) How do households collect, store, and treat their water supply?

Collection from sources varies with the seasons. During the dry season boreholes are the primary drinking water source followed by water collected from reservoirs. During the wet season rainwater becomes the dominant drinking water source. This change in source also affects how far people have to travel to collect their water, 24% of survey respondents had to travel less than 1km during the dry season to collect water, while in the wet season that shifts to 47% of respondents. We also found the majority of water collectors were males (60% of respondents) or individuals within the 18-33 year old age bracket (62.5% of respondents) while only 40% of women and 18.8% of people under the age of 18 were responsible for collecting water.

Of particular importance was how water is stored and treated in the home prior to use. 78% of households reported that they store their water for more than a day, but only 54% of those who store water keep their storage container sealed. Unsealed storage containers allow for the possibility of contamination, essentially rendering the benefit of collecting from an improved source useless.

Treatment methods vary depending on the water source that was used. Approximately 30% of households surveyed do not treat their drinking water during the dry season, of those only 22% of households are getting their water from reservoirs, the only reported surface water source. During the dry season the percentage of people getting their main drinking water supply from unimproved sources shifts to 28%, up from 8% in the wet season.

3) What measures can be implemented to ensure the community's access to a sufficient supply of potable water?

- Water storage methods including cleaning and covering containers should be addressed.
- Treatment for microbial contaminants is most easily done through boiling water at a rolling boil, approximately 100°C, most bacteria will be rendered inactive after five minutes of boiling.
- Any water collected at the reservoirs or any other surface water sources should be filtered, preferably though a multi-stage filter, before any treatment.
- Properly encasing bores to a reasonable depth and sealing the bore heads to prevent contamination from surface water.
- Assist in educational campaigns on the following: water treatment, particularly adequate boiling practices; proper water storage methods; and sanitation programming.
- Transparent and open communication with the Migyera Town Council.
- The CALU well should be monitored closely to check that the fluoride content does not surpass recommended standards.
- Community workshops on installing and properly maintaining the rainwater collection systems.
- A groundwater management plan determining the recharge rate of the surrounding area, continued chemical & bacterial monitoring, and it would be advisable to collect additional information on the ground water to mitigate water stress during the dry season.

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Introduction

This master's project seeks to evaluate current, local perceptions of quality, access, distribution, and use of water resources in Migyera Town Council, Uganda in order to provide recommendations to the client, ChangeALife Uganda, for future water related projects. ChangeALife Uganda (CALU) is a non-profit located in Uganda that focuses on providing education and health care, improving the livelihoods of children. This project is of importance to CALU because water quality and quantity is strongly connected to long-term health, especially for children who are more susceptible to water borne illnesses. Water quality and quantity and access to these sources are also commonly seen as an indicator for both health and livelihoods and is an important marker to determining future success in these areas. At the request of the client and corresponding with their mission, this project evaluates the quality of water, looking at both potential microbial and chemical contamination, in order to ascertain if treatment is required before water distribution and consumption. Closely tied to health, sanitation practices were investigated through community surveys and on ground observations with the goal of mapping locations of possible contamination and promoting good hygiene practices. Combined, these issues helped determine the driving questions for the project:

1) What are all the accessible water sources in Migyera Town Council and what are their contamination levels?

2) How do households collect, store, and treat their water supply?

3) What measures can be implemented to ensure the community's access to a sufficient supply of potable water?

The project consists of three parts to assess the driving questions: water quality testing (both chemical and bacteriological), household surveys, and ground truth points for further geospatial analysis. In order to examine the relationships between these three parts, the first section of the report introduces the project site with a discussion on the importance of access to water and high water quality to community health and livelihoods. The second part of the report details the methods used, both in the field and at Duke University in the creation and implementation of the survey, collection and processing of bacteriological and chemical water samples and compiling GPS points. Section three provides the analysis of all the data. The last section offers recommendations for the client. Appendices at the back include supplementary material such as copies of the final survey and full results of the water testing analysis.

Project Background

Water quality and quantity is closely tied to long-term health, and access to sources with good water quality has long been viewed as a measure for health (Gundry, Conroy, and Wright 2003, Machdar et al. 2013). Although much progress has been made towards increasing access to improved water supplies, there is a significant disparity between those living in urban and rural settings (UNICEF and WHO 2014). In Uganda, 85% of the total population of 34 million lives in rural areas, including the project site, Migyera Town Council. Of those rural Ugandan households, 70% have access to an improved water supply (UNICEF and WHO 2014).

For those fortunate enough to have consistent access to water, the quality of the water can be a serious issue. There are many potential causes of contamination in water sources, including contamination from human activities and naturally occurring elements. One of the most prevalent sources of water contamination in Africa is pathogens[1] (Machdar et al. 2013). Housed, perpetuated, expelled, and transmitted by humans, enteric pathogens[2] are spread through contact with the fecal matter of a human or animal and subsequent person to person contact. Frequent hand washing and good hygiene practices can prevent their spread to others. Contracting an enteric pathogen such as Salmonella or E.coli physically manifests with symptoms like diarrhea, dehydration, fever, and vomiting. When left untreated, especially in areas with poor sanitation and hygiene practices, it can create devastating health impacts at the community level (Ashbolt 2004). For young children, contracting an enteric pathogen can result in malnutrition, absence from school, and stunted development. Overall, this form of contamination causes the death of approximately 1.2 million children annually (UNICEF and WHO 2014).

While microbial contamination of drinking water is typically tied to hygiene and sanitation practices, finding the origin of chemical contaminants can complicated and costly because the physical environment is the source of pollution. The chemical composition of groundwater is especially important in areas where it is the primary source of drinking water. Extended exposure to even low levels of certain naturally occurring elements can cause exponential

[1] Viruses, bacterium, protozoans, parasites, and other organisms.
[2] Microorganisms and microbiota that reside in the intestines of mammals. Innumerous quantities populate the gut, so inevitably some are excreted via fecal matter.

damage to the human body. Again, the detrimental health effects are magnified in children, given their miniature size and their vulnerable developmental stage.

Naturally occurring groundwater contaminants are introduced via weathering, leeching, and percolation through mineral deposits. The concentration of the chemical depends on the characteristics of the water (temperature, pH, and alkalinity), the sediment in the aquifer (solubility of the minerals and the composition of the geologic formation), and contact time (Jha et al. 2013). Given the site of our project's location, specifically within the East African Rift Valley, previous studies, and its reported geology, the immediate chemical constituents of concern were arsenic and fluoride (Rango et al. 2009, Rango et al. 2010, Rango et al. 2012, Rango et al. 2013).

Long-term exposure to substantial amounts of either of these two natural elements physically manifests, but distinctly. Arsenic poisoning appears as wart-like blemishes on the hands and tongue. Whereas any exposure to arsenic is bad, as it is a proven carcinogen, fluoride presents a considerably more complicated public health problem. While used as a lesser additive to treated drinking water in developed countries as a means of fortifying growing permanent teeth in children, ingestion of large quantities of fluoride, such as those found naturally in some groundwater, can have the opposite effect. Children are vulnerable given that their mind and body are undergoing formation and development, which makes them especially susceptible to the health impacts of these chemicals.

By addressing these health concerns, not only will the individual people suffering from these ailments be positively affected, but these efforts can have far-reaching influences in the country. With the improvement of one's health, an individual who might otherwise be ill can enter the workforce, improving the economic production and the community's overall success (Moffat, Motlaleng, and Thukuza 2011, Georgiou et al. 1997, Olajuyigbe and Fasakin 2010).

Project Area Background

Located 140 kilometers north of Kampala, Uganda's capital, is the Migyera Town Council. Formerly designated as a parish within the Nakasongola district in the central region of Uganda, the project area is divided into 7 villages. The newly structured Migyera Town Council maintains similar external boundaries, but the names and number of villages within its lands are expected to change as the regional governing body establishes itself. Given that all fieldwork was conducted in the summer of 2014, before boundary changes were made, this report will continue to refer to the Migyera Town Council as the area composed of the seven original villages: Migeera A, Migeera B/ Dembe Zone[3], Kitwe-Kyambogo, Kyabachwezi, Kyangogolo, Kyakala, and Nalukonge.

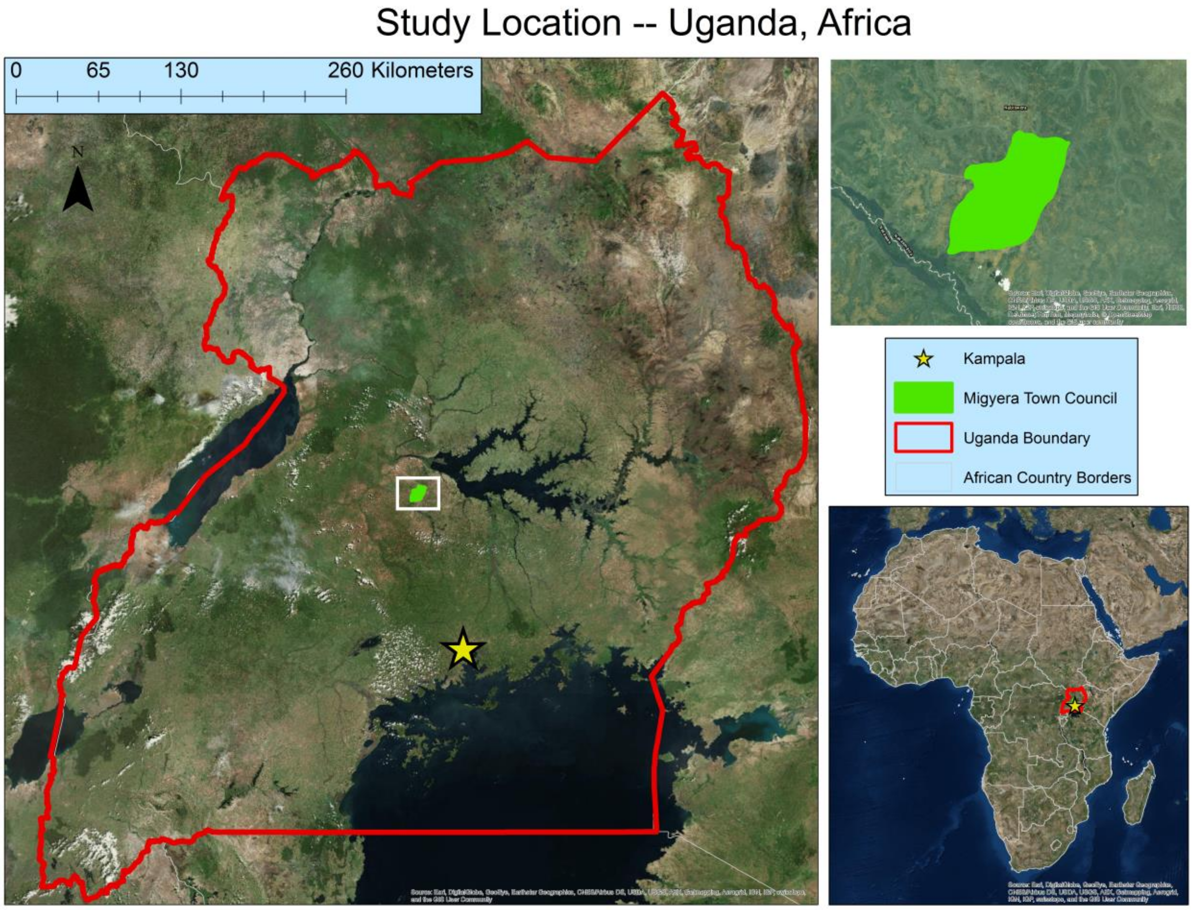


Figure 1. Study Location: Migyera, Uganda

Situated along the Kampala-Gulu highway, the only major road that connects the northern part of the country to the capital, Migyera is a popular overnight resting place for truckers transporting goods between the southern and northern parts of the country. Although all the previously listed villages are located within the same Town Council of Migyera, different villages have different primary occupations based on their location. The notably urban villages of Migeera A, Migeera B/Dembe Zone, and Kitwe-Kyambogo cater to the passing vehicles with hotels, restaurants, bars, and service shops. Migeera A has the only gas station before the area's next major city, Masindi, 80 km north of Migyera.

[3] Both terms, Migeera B and Dembe Zone, are used interchangeably within the Town Council for the same village.

In comparison, rural residents of the Nalukonge village primarily earn their living as cattle herders. At the same time, the primary source of income for the entire region includes agriculture and charcoal production. Most residents also participate in some level of subsistence farming. This village-to-village distinction is especially important when examining water problems, as some affect the Town Council as a whole and some are individual problems within a village.

Population & Culture

Migyera is demographically diverse, in part due to the population growth the community has experienced in the past decade. The two largest ethnic groups in Migyera are the Baruli and the Baganda, both native to the Buganda kingdom, the largest of Uganda's three founding kingdoms. While tribes have their own languages, most of the population can understand Luganda, the prevailing language in the community, and English, the country's official language. Likewise, Migyera has several religions that represent the population. The dominant religions include Christianity, Islam, and Catholicism. The religious variety highlights different personal practices with varying individual behaviors and the religions themselves hold political significance within the country.

Environment

Central Uganda is the home of several national forests, a few wildlife conservation areas, many endangered wetlands, and huge expanses of managed agricultural and pastoral lands. For much of the rural population, these lands are the sole source of sustenance. More generally stated, these lands and their management provide some sort of livelihood for a majority of these residents. In turn, much of what governs these land uses is the availability and quality of the water in the region.

Geology

The underlying geology of the region strongly influences the hydrology and water availability. Along with 90 percent of the country, the geology of the study area and the greater Nakasongola district is characterized by a crystalline basement complex system dating back to the Precambrian age[4] (Development and (WWAP) 2006). These rocks are mostly

[4] This historic era starts with the formation of the planet and ends 600 million years ago with the beginning of the Cambrian age.

undifferentiated gneisses, which are rocks formed by higher temperatures and pressures, like granite, schist, phyllite and quartzite (Howard et al. 1992). Over time, these crystalline structured rocks have weathered[5], causing fissures under the surface of the earth, through the bedrock which houses the groundwater. This weathering process has created a fractured aquifer system, where separate aquifers become connected by the cracks that have formed within the bedrock. This allows for water, chemicals, and bacteria to flow in between aquifers whereas before they remained self-contained. Overlying the bedrock, intensive weathering leads to the creation of a layer of unconsolidated rock derivatives called the regolith, which also acts as a repository for groundwater. The thickness of the regolith varies across the country and within the study site. Past well exploration has found the regolith to be up to 30 meters thick, which indicates the potential for the storage of large amounts of groundwater. However, the thickness of the regolith also makes it difficult to access the stored water as it is very deep under the Earth's surface.

Hydrology[6]

Depth to the water table varies seasonally and across the landscape. In the Migyera Town Council, the average depth to the water table is approximately 40 meters; however, many boreholes are sunk to depths of 70-80 meters in order to access water located in the fractured bedrock. The yield of the aquifers such as those found in Central Uganda depends on transmissivity[7] and storage capacity, which is not well known for the area. The transmissivity of the region is low, meaning that water is slow to move throughout the bed and is associated with the low yielding boreholes of the area (Howard et al. 1992).

Water Availability

Similar to the country as a whole, the water supply for residents in Migyera Town Council comes from sources including groundwater, surface water, and rainwater collection. Groundwater is accessed through deep boreholes and then distributed to the population through public taps, a piped water system with an outside spigot, or private vendors. A majority of the boreholes in the

[5] The physical breakdown of rocks or the earth's surface by means of physical, chemical, or biological processes.
[6] Data available on the hydrology and groundwater is limited to the county level, which is Nakasongola in the case of Migyera Town Council. Parish, Town Council, and/or village level, is rarely accessible from government sources, so much of the information on the dominant hydrologic processes of the study area was provided by CALU, which in turn had contracted Universal Water Consultants, a professional firm based in Kampala, in its pursuit of constructing a private borehole. These reports present both information collected onsite by the contractors and from more bureaucratically restricted government records.
[7] Transmissivity is the rate of horizontal water flow through an aquifer.

study area were installed by the government, who is also responsible for their maintenance. As of July 2014, a third of the government boreholes visited within the subcounty of Nabiswera were not functioning[8]. In addition to functionality of the hand pump and well casing, the seasonality of the water table poses another obstacle for locals. Simply put, some wells do not work during the dry season. This is most likely due to the dropping water table, which occurs because of increased water extraction during that time over year and decreased recharge as precipitation declines.

There are two government built dams, creating surface water reservoirs[9] in Migyera Town Council. Surface water is collected by trudging into the shallow end of the dam and submerging jerry cans or other water containers. In the case of the Migeera A dam, humans and livestock share the same water source, whereas in Kyakala, acacia branches make a barrier that prevents cattle from accessing the dam. When livestock has access to water sources, it is likely that the microbial contamination will much higher. Bacteriological contamination of dams from humans and animals is not the only concern, people were observed directly washing vehicles near the edges of the Migeera A dam. Runoff from the highway is also directly diverted into the dams through constructed culverts making chemical contaminations a concern for some but not all dam water sources. The surface water dams are highly susceptible to changes in precipitation, the Migeera A dam has been reported to occasionally completely dry up during the more extreme dry seasons, further putting pressure on boreholes to supply water.

The study area does not have great topographical variety; however, many places experience seasonal surface water pooling due to natural formations or sometimes anthropogenic intervention. Many private dams were identified during the course of the project. In many cases, water from these private dams, and sometimes even public ones, are pumped into large trucks and sold house to house by vendors. According to locals, this practice occurs during both the wet and dry season. However, it is during the dry season that vendors along with bottled water become more prevalent sources. This issue with this is that many people may not be aware of where the water is coming from when buying from vendors. Vendor water, however, was not included in the chemical and bacteriological testing aspect of this project.

[8] Boreholes may be non-functioning for a variety of reasons. The Directorate of Water Development shows the three leading causes for a non-functioning borehole are technical breakdown of the borehole pump, a dry or low yielding borehole, and leaking at the borehole (2010). In Migyera we experienced one borehole that was non-functioning due to vandalism.

[9] The water reservoirs are commonly called dams within the community and will be referred to as dams throughout the remainder of the report.

When available, many residents and institutions practice rainwater collection and storage. The designs and methods for capturing rainwater varies greatly from house-to-house. While a popular practice, little is known about the specifics of rainwater use and storage in the study area. Based on direct observation of households that did have a rainwater collection systems, most were crudely constructed consisting of gutters leading into a variety of storage containers, most of which were kept uncovered.

Water Management and a Changing Climate

An added complication to managing water sources is precipitation patterns. Eastern Africa experiences a bimodal annual cycle of precipitation, creating two rainy seasons and two dry seasons (Nicholson, 1996; Mutai and Ward, 2000; Lyon, 2014). Following suit, Migyera also experiences two distinct cycles of a wet and dry season. The first dry season lasts from December to February, the first wet season from March to May, the second dry season from June to August, and the second wet season from September to November.

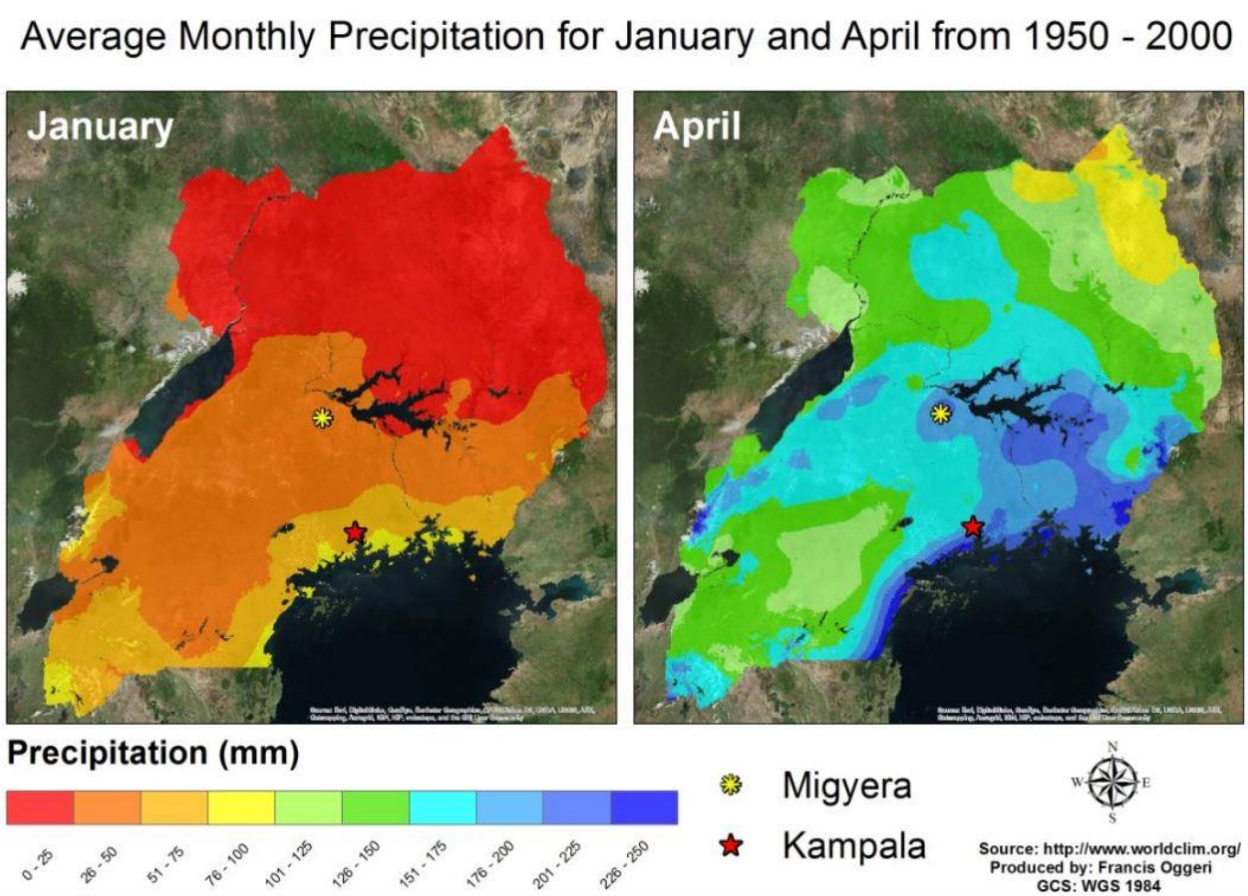


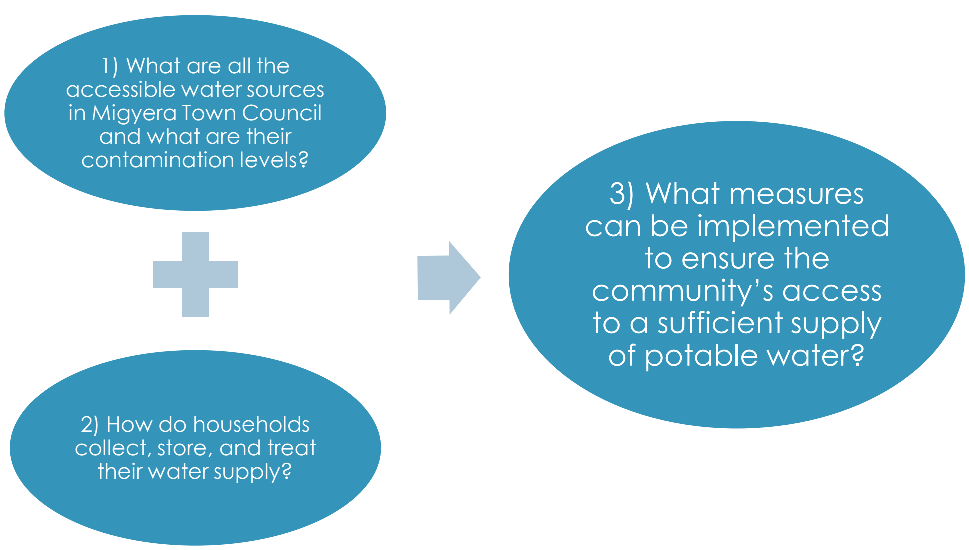
Figure 2: Representation of precipitation during the peak dry (January) and peak wet (April) seasons for Uganda.

Each season provides its own set of challenges. In the dry season, water availability is low, which creates time constraints on those in charge of water collection. Additionally, many community members choose to collect from free surface water sources, such as government dams. During times of limited water supply, these open sources dwindle, leaving less water and more pollutants (microbial and chemical) per liter of water. On the other hand, in the wet season, large amounts of precipitation lead to excess water and surface flow. These superficial waters can pick up, carry, and deposit contaminants in a water source that they would not have reached otherwise.

While aforementioned weather events were formerly dependable, first-hand accounts of local people suggest that these formerly distinct seasons are becoming more variable, more extreme, and the temporally less reliable. As a result, water supply management has had to become more dynamic. For example, longer dry seasons are making water storage a necessity, but storing water opens new possibilities for contamination with the potential for debris to enter the storage container. With rain water a major source for many people during the wet seasons changing climatic patterns my increase the pressure and dependence on other sources. With a potential shift in climatic patterns in the future the community may also be forced to find a new supply to ensure a sufficient supply of potable water.

Methods

Our research consists of three primary components: household surveys, water quality testing, and geospatial information. These three avenues were selected to provide a holistic review of our driving questions:



Determining the level of contamination through bacteriological and chemical water testing and collecting GPS points allows for us to meet our first goal of determining accessible water sources and contamination levels. Our second goal, of assessing water collection methods, treatment and storage within homes was fulfilled through the household survey collection. Combined, the independently collected water quality samples and GPS points allow us to corroborate the self-reported answers from the household surveys through additional analyses. As it was important to determine the realities versus the perceptions of water quality and access, it was important to gather both self-reported and independent data. All together, these three avenues enable us to provide recommendations for our client. This section details the methods for the collection of these data categories.

Household Surveys

A survey sample size of 124 households was calculated using the equation:

$$n = \frac{\left(\frac{P[1-P]}{\frac{A^2}{Z^2} + \frac{P[1-P]}{N}} \right)}{R}$$

Where n is the required sample size, N is the number of households in the community, P is the estimated variance in population (0.1, 0.3, or 0.5), A is the precision desired (0.03, 0.05, or 0.1), Z is 1.96 for a 95% confidence interval, and R is the estimated response rate (0.9) (Watson 2001). In order to determine our household sample size, we used population figures from the 2002 census and a population growth rate of 3.3% to estimate the 2014 population. From the calculated household sample size, the number of surveys conducted in each village was determined by the number of households in the village so as to conduct a random sample on a proportional basis. Adjustments were made on this calculation based on direct communications with local village and community leaders. For some of the villages, particularly those furthest away from the highway and in the more rural areas, we were informed that population has been decreasing while the villages located along the highway have been increasing. For example, in the village of Nalukonge, one of the more remote rural villages, the population was actually half the size of our calculated population. Therefore, although the number of household sampled within each village was not the same, the representation of the village into the total households surveyed was equal to if every household had been sampled.

Development of Survey

The initial survey was developed by combining multiple resources from previously tested international organizations and academic scholars.[10] Five community focus group meetings were conducted, with Duke University group members meeting with key constituencies including a Volunteer Community Health Team, mechanics, women who run the market, a local restaurant owner, and the Boda-Boda drivers.[11] In these community focus groups, the Duke team pre-tested questions for the household survey to determine cultural relevancy and understanding. For example, one of the discrepancies we discovered was the use of the word 'toilet' versus using the word 'latrine' in our questions. The community members did not view these terms as interchangeable which caused some initial confusion. After these general community group discussions, we hosted four focus groups, two in Migeera A and two in the village of Kyangogolo to test specific survey questions. The focus groups were divided by gender, each led by a translator and a Duke group member of the same gender. The focus groups in Kyangogolo were of special importance as they contributed a more rural perspective to the questions. There the men's group had 7 participants while the women's group had 10 participants. The first women's focus group in Migeera A ultimately was excluded from consideration since a female translator was not available and there is concern that the presence of a male translator skewed the participant responses.

This survey developed from all of the sources previously listed, and changed in accordance to feedback received in the focus groups, was given to our client, ChangeALife Uganda for review. During this time, we located enumerators who would be available to go out on a daily basis to conduct the surveys. All of the original enumerators were recommended by the ChangeALife Uganda field officer and selected based on their existing relationships with the client, ability to speak English, and aptitude for translating from English to Luganda and back. Three of the first four enumerators involved in the project were school teachers in the local schools while the fourth enumerator was the CALU field officer. After the client approved the initial survey, the enumerators spent a day being trained by the Duke team to ensure understanding of the questions. The questions were individually reviewed and the enumerators took turns administering the survey to one another in both English and Luganda, ensuring accurate

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[10] These resources included the World Bank's *Designing Household Survey Questionnaires for Developing Countries: Lessons from 15 Years of the Living Standards Measurement Study* and a Duke PhD student, Chris Paul, who has been conducting household surveys in Ethiopia for the past 3 years.

[11] A Boda-Boda, or bodaboda, is a bicycle or motorcycle taxi, typically found in East Africa. In the context of Migyera, the Boda-Bodas were typically motorcycle-taxis.

translation. The day following the training the enumerators conducted a field test, or pilot survey, resulting in 14 test surveys completed within Migeera A and Migeera B/Dembe Zone. The enumerators were divided into three groups, with one group consisting of two enumerators, to travel with the three Duke team members who were present in case any questions occurred during the field testing. This also allowed the Duke team members the opportunity to test the collection of GPS points which they would consistently capture once the official survey got underway.

The pilot survey samples were all collected within one day, and only minor changes were made to the survey before beginning collection of surveys that would contribute to the final household numbers. The survey was administered in the 7 villages within the Migyera Town Council. Table 1 below contains the measures for the number of households per village that needed to be visited based on the original survey size calculation and the actual number of households that were visited in each village during the administration of the survey.

Table 1. Village Sample Size for Household Surveys

Village Name	Calculated Sample Size	Actual Collected
Migeera A	20	23
Migeera B/Dembe Zone	46	48
Kitwe-Kyambogo	30	30
Kyabachwezi	8	9
Kyangogolo	2	2
Kyakala	15	16
Nalukonge	3	4

Protocol in Household Selection

Households were selected using the right hand rule, which consisted of starting on the right side of the street and following the line of houses on the right. Each village had a designated skip number, calculated using the density of houses in the village and the number of total households in the village. The skip number represented the number of houses that were passed by the enumerators between households that were included for the survey. This procedure was included to ensure the survey consisted of a random sample of households throughout the villages.

Before verbally completing the survey with one of our enumerators, the participant would be read, and verbally agree to, a survey consent form which can be found in the appendix. If the participant accepted participation, the remainder of the survey would be read by the enumerator to the participant. If the participant declined to take the survey, no replacement house was chosen and the household was included as a response for the total number of household surveyed in that village.

If no one was home when the enumerator first visited, the household would be re-visited once for a total of two visits to the household. If the participant was not home during the second visit, then a replacement household was selected using the right hand rule and skip number from the last household that was visited in the village.

On some occasions, the enumerator visited at an inopportune time for the household member. In these instances, the enumerator and household participant would establish an agreed upon time for the enumerator to return. If, when the enumerator returned, the household again asked for the enumerator to visit at another time, the household was counted as having declined the survey and no replacement household would be chosen. If the household member was not home when the enumerator returned, it would count as a second visit and a replacement household would be selected.

In any circumstance, an enumerator would only visit one household on two separate occasions and follow the above protocol to determine whether or not the household would be counted or replaced.

Survey Data Input

All of the surveys in Uganda were recorded on paper. Prior to leaving the country the majority of the surveys were scanned into a computer in case of any accidents that may result in the loss of the surveys during transit. In order to create an electronic database with all of the survey results, the survey was re-created in an online survey collector, Qualtrics. Given the breadth of the original survey, certain measures were taken to streamline the data input, namely skip logic. Additionally, using Qualtrics permitted the team to further improve the consistency of the data set by applying meticulous input protocol, which was found to be extremely useful later when converting distance and time measurements to uniform units.

Multiple iterations of the electronic survey were tested and revised to ensure that the data was recorded properly before the final survey was launched. Upon its completion, Duke team members input each original paper survey into the Qualtrics based survey.

Out of all of the paper surveys, only one survey was excluded from inclusion into the final data set as it was revealed by one of the enumerators that the household participant did not reside within the Migyera Town Council. In other instances where a survey was not fully completed or a section was found missing, the portions of the survey that were completed were entered for inclusion into the dataset.

Challenges

In the initial plans to develop and test the survey questions, we wanted to speak with random community members, prior to our focus groups, to gauge understanding and effectiveness of questions. The ChangeALife field officer said that this would not be culturally acceptable and instead arranged for the small community group meetings that were mentioned earlier. A similar problem arose in the formation of our focus groups. Whereas it was our goal to conduct random focus groups after advertising the meeting in a neighboring community we discovered that the first set of focus groups were by invitation and within the Migyera Town Council boundaries. This was of concern as the majority of the participants lived within the urban villages of Migeera A and Migeera B and all had relationships with the client. Additionally, at this time no female translator had been found so both the all-male and all-female groups were conducted by a male translator. Worrying that the demographics and the presence of a male translator in the all-female group would skew the answers in the focus group and not be representative of the entire Town Council, we found it necessary to set up the second set of focus groups in Kyangogolo, a more rural area of the Town Council.

However, the location of both the focus group in Kyangogolo and the pilot survey within Migeera A and Migeera B led to later problems. While we had originally planned to keep our testing, both in the focus group and the pilot separate from where we were going to be conducting the survey eventually, the field officer said that it would be very difficult and time-consuming to do and would delay our ability to start collecting surveys. However, while collecting surveys in the areas where the focus groups and pilot surveys occurred we ran into several instances of re-visiting participants. This influenced our skip numbers or starting locations in these areas, often requiring us to start at the second household on a given street instead of the first. This was less of a problem for the survey results than it was an inconvenience to the households we were visiting.

Another obstacle we faced during the duration of our survey collection was the lack of population and statistical data in the area. Knowing the population, both for the Town Council and the individual villages, was important for our calculations so we could obtain a proportional response from each village into the total surveys collected and ensure we were truly collecting a random sample. Uganda was supposed to have its most recent census in 2012 which ended up being pushed back to fall 2014 due to lack of resources. This meant that the most recent census data that was available was from 2002. While we did make population projections for the Town Council and villages based on the population growth rates and the 2002 population numbers, we were able to refine our accuracy by talking with members of the Town Council and the leaders of the villages within the Town Council. Although this took significantly more time to determine, the numbers were more reliable than the population projections on their own.

Ultimately, one of the biggest challenges in administering the survey came with the training and retention of the enumerators. Throughout the project we used five total enumerators, all of them working part-time. Most of the enumerators also worked at the nearby primary school so they were only available in the afternoon. Of the five, only one of the enumerators had any previous experience administering surveys which meant that training the enumerators took up a significant amount of time. Three of our four initial enumerators left the project after three weeks as they no longer had time to go out and visit households due to other obligations to the client's projects. Two potential enumerators were identified that were then trained in the same manner as the original four, with the added benefit of the one enumerator that was continuing on with the project assisting in the training. Of the two newly trained enumerators, we kept one along with our one continuing enumerator to complete the household survey collection.

In each of these challenges, cultural differences and communication barriers were primary contributing factors.

Water Quality Testing

Two types of water quality testing were executed: bacteriological and chemical. The bacteriological testing was performed in the field, while the samples for chemical testing were collected in the field and then shipped to both the Kampala National Lab and Duke University for analysis. Both analyses enabled us to determine levels of contamination. It was important for the bacteriological testing to perform the tests for both the source and household water level to determine if contamination was coming from the source or if it was being introduced during the collection, transportation, or storage.

Bacteriological

In-field Testing

All of the bacteriological testing was completed using a DelAgua field kit, generously donated for our use by DelAgua. The important aspects of the kit included an incubator, a filtration apparatus and vacuum cup, and a pressure cooker for sterilization. Prior to collecting and processing water samples, all of the equipment was sterilized using the pressure cooker and the culture medium necessary to grow the colonies was prepared. The membrane, placed in the culture medium, grew thermotolerant colonies, also referred to as total fecal coliforms. After being incubated for an appropriate amount of time, the colonies that grew on the membranes were counted in order to assess the total fecal coliform count within that sample.

Procedure and Protocol from Household Collection

Water samples for bacteriological testing were collected at households and public water points. All samples were processed within a three-hour time window from collection to being placed in the media. The majority of the time, samples were put in a cooler containing ice or frozen water bottles in order to preserve the integrity of the sample. Household water samples were collected at the end of that household's participation in the household survey, with enumerators asking for samples of treated drinking water at every other house. Samples were only collected with permission of a household member. The household member was asked to provide a small sample of drinking water and the sample's source of origin. The time the sample was collected was recorded on the sample container in order to ensure that the sample was processed within the appropriate amount of time.

DelAgua Kit Procedure

Since multiple enumerators and Duke University team members were completing household surveys at the same time, it was not always possible to immediately incubate the samples. The majority of the time, samples were processed in a vacant room at ChangeALife Uganda's St. Francis Health Center. Only occasionally were samples processed in the field. Gloves were worn at all times when processing samples. The procedure for either instance was the same and is as follows:

1. Using a sterilized vacuum cup, filtration apparatus and tweezers, a membrane was placed underneath the filtration funnel. The funnel was then secured.

2. Often one sample was processed 2 or 3 times and diluted to different factors in order to get multiple, and more accurate readings of the fecal coliform counts within the sample. Common amounts were 10mL, 5mL, and 1mL. The samples were poured carefully, using the filtration funnel as a guide to ensure that the membrane remained undamaged. If 5 mL or 1 mL of the sample was used, distilled water was used to dilute the samples due to the potential for high total fecal coliform readings. The total amount filtered in these cases was 100 mL.
3. Using the pump attached to the filtration apparatus, water was drawn through the membrane and into the cup below.
4. The filtration funnel was then removed, so the membrane could be carefully placed in a petri dish containing an absorbent pad soaked in the culture medium.
5. All petri dishes were marked with the sample ID, volume processed, source of the sample, time and date, and who processed the sample. The petri dishes were then placed within the incubator for the 18 hour incubation cycle.
6. After the end of the incubation cycle, the petri dishes were removed and all yellow colonies were counted by two Duke group members to verify the numbers. All colonies were counted within the first 15 minutes from removing the petri dishes from the incubator since as the membranes cool, the colors of the colonies will change.

Challenges

There were several challenges that were experienced during this process. One of the first challenges we faced was the lack of lab tools. Due to our location in rural Migyera and no readily available transport we often had to wait for someone to bring us supplies from Kampala such as pipettes to dilute our samples before processing. Other issues acquiring supplies included finding methanol for sterilization of equipment. Prior to receiving the methanol we would wash and sterilize our petri-dishes by boiling and washing with mild detergent. There were some concerns that detergent residue left on the dishes could have affected some of the samples. For the preparation of the samples we needed distilled water with a pH of 6.5 to 7.5. Without access to distilled water, bottled water was used, but only after confirming with DelAgua that bottled water without traces of chlorine would be a suitable replacement.

When collecting samples we often had two enumerators out at once, making it difficult to process the samples in the field as the enumerators at times were not located near one another. Preparation of the samples preferably needed to be completed within 3 hours of collection, but could be processed up to 6 hours after collection if placed on ice; however, access to ice was not readily available so most samples were processed by the three hour mark. This time restriction did result in some samples not being processed.

A problem caused by our oversight included the DelAgua incubator which ran on battery power. It was recommended that the battery be charged at every opportune, but at minimum, needed recharging at least once a week. For the most part, the timeline in which to charge the battery was reliable, however, access to electricity was not. During our tenure in the St. Francis Health Center the outlets were not always providing electricity, and as a result, not charging the battery even when the Duke team thought it was charging. This lapse led to the loss of a set of samples as the incubator was not charged when it was needed next. To resolve this issue, the incubator was moved to and from different rooms when in use and being charged.

Our final challenge related to what type of contamination we wanted to test for in the household water samples. Our initial plan was to test for E.coli as this particular bacterial contamination cannot be found in nature, but only in the intestines of mammals (Field and Samadpour 2007, Savichtcheva and Okabe 2006, Organization 2012, WHO 2011). As such, it is typically considered the best indicator of fecal pollution and the presence of pathogens. However, a misunderstanding on the type of medium we thought was ordered versus the type of medium that was received meant that we had a medium that detected total coliforms, a wider range of bacterial contamination, but was unable to detect only E.coli. We searched for an alternative media in Uganda, but it was too cost prohibitive to switch mediums. Ultimately we were still able to perform our tests, but were unable to quantify the number of E.coli present in each sample.

Chemical Testing

Equipment for Collection

To complement the bacteriological household water testing and provide an enhanced insight into the region's geochemical make-up, the team prepared and carried 40 chemical sample kits with them to Uganda. The sample kits are standardized for Dr. Avner Vengosh's lab, with each kit, enclosed in a gallon Ziploc bag, containing the following: 7 Thermo-Scientific Nalgene High-Density Polyethylene bottles (color coded for ease), Syringe plunger, 0.45 micron filter, and arsenic speciation bottles and filter. Given the limited confirmed information about the number of wells and boreholes, the team favored bringing an excess.

Table 2. Description of Chemical Testing Field Kit

Bottle Color	Test to be performed	Purpose	Filtered/Not Filtered
Yellow[12]	ICP-MS & DCP	Measure metals	Filtered
Red	IC	Measure anions	Filtered
Big Green	N/A	Measure isotopes	Filtered
Little Green	Depends on other results	Measure O and H isotopes	Not Filtered
Red & Black	Titration	Measure Alkalinity	Not Filtered
Yellow & Red	N/A	Bind Arsenic 5	Filtered
Yellow & Green	Arsenic Speciation (use ICP-MS)	Measure Arsenic 3	Specially Filtered

Procedure for Collection

Sampling protocol was established prior to arrival in Uganda. Chemical samples were only collected at public access points (boreholes, dams, and taps, and rainwater collection). Collecting at participating households was deemed unnecessary because the chemical makeup of the water would not change significantly from the source to the point of use location. In addition to adopting the Vengosh lab's sampling format, the Duke team chose to use its sampling protocol. To see the full sampling methods, according to water source, please refer to Appendix F.

As per the request of the client and the benefit of quicker results, it was agreed that some samples would be taken to the national water testing lab in Kampala for analysis. Given this condition, the Duke team altered its sampling protocol slightly in order to take duplicate sample kits at geographically and socially important locations with the intention of sending one of the kits to Duke and one to Kampala for analysis.

In total, 33 samples were taken in the Migyera Town Council and surrounding Nakasongola district. As several of the community boreholes were non-functioning, either from vandalism or mechanical problems, there were ample samples kits left over. Given the length of time in country, collecting a significant time series was not a feasible option. The samples that were taken outside of the Town Council were done so in order to contextualize and compare the results from the Migyera samples.

Processing in Kampala

Taking advantage of the national water testing lab in Kampala offered both the Duke team and the client the convenience of receiving preliminary results before more extensive testing

[12] Yellow bottles were acid washed in order to better preserve the trace metals present in the sample.

occurred at Duke University. As cost was a determining factor, the project budget influenced the number of samples tested and the number and type of constituents selected. In total, eight samples were given to the national water quality testing laboratory for analysis. The main parameters chosen were: pH, alkalinity, calcium, bi-carbonate, fluoride, iron, arsenic, salinity, and aluminum. The results table from the testing in Kampala can be found in Appendix G of this report.

Processing at Duke

The remaining samples not tested in Kampala were sent back to Duke University via DHL. As per an agreement made with Dr. Vengosh and his lab, there would be no cost to the team for any tests run on the samples. In addition to free water sample testing, the advanced equipment at Duke made it possible to perform broad spectrum analysis, testing across many parameters, and at the best detection levels currently available to scientists.

To better comprehend the water quality and geochemistry in the region, three tests were run on the 25 samples: Inductively coupled plasma mass spectrometry (ICP-MS), Ion-exchange chromatography (IC), and Direct Current Plasma Emission Spectrometer (DCP) tests. Sample preparation was done by the Duke team, subsequent testing was completed by the Thermal Ionization Mass Spectrometer Facility at Duke University. Given the team's hypothesis about the presence of potentially hazardous chemical constituents in the water samples, ICP-MS was prioritized above the other two tests.

Procedure for Processing at Duke

Before any chemical testing could be performed, two tests had to be performed on the samples. First, the total alkalinity was determined using titration, effectively determining the acid-neutralizing capacity of each water sample. Second, some concern arose with respect to the electrical conductivity (EC) probe's accuracy in the field, so the measurements were taken again in the laboratory using a calibrated and reliable conductivity meter. The alkalinity and EC were then used to calculate the dilution factor for each water sample for each of the three tests. The samples had to be diluted differently depending on the test because each machine has an ideal conductivity range, within which it can most accurately detect the presence of constituents. The dilution calculations were done in Excel.

Table 3. Chemical Processing Tests Completed at Duke

Test Name	Acronym	Constituent	Bottle Color
Inductively Coupled Plasma Mass Spectrometry	ICP-MS	Trace metals	Yellow
Ion-exchange Chromatography	IC	Anions	Red
Direct Current Plasma Emission Spectrometer	DCP	Cations	Yellow

Once prepared, the diluted samples were run through their corresponding testing equipment. Prioritization was given to ICP-MS, given our hypotheses for high arsenic and fluoride levels. Results from the test were made available in an Excel spreadsheet; however, the values given were raw data and did not account for the dilution factors we had used on some of the samples. Using the precise measurements recorded during the sample preparation process, the dilution factors for each sample was calculated for each test and applied to the raw data. To further simplify the data, all units were converted to parts per million (ppm).

Challenges

Anticipating potential problems we might encounter in the field with chemical water sampling was by far the largest challenge faced in preparing for our departure for Uganda. We had to plan for every eventuality, knowing that we did not have accurate information about the number of boreholes, especially the number of functional boreholes in the area of study. Inadvertently, by bringing more kits than we predicted needing we ended up solving an unforeseen problem, extremely turbid water. We packed extra filters as all of the samples had to be filtered during collection and we imagined some samples would require extra filtration. However, if every kit brought had been used, we would not have had enough filters considering the number of surface water sources that had to be sampled. As an example, the first completed water sample kit of the community dam took a total of 8 filters to complete, but kits were assembled with only 1 – 2 filters per recommendations and experiences from colleagues in similar environments. Needless to say, the turbidity of the water was surprising and much higher than experienced in comparable areas.

Despite our efforts to plan for the impossible, we still encountered challenges. As mentioned above, we experienced problems with our EC probe. Upon returning from the field, we saw some inconsistencies in our recorded measurement. To quell our uncertainty and ensure the most accurate chemical analysis of the samples, we chose to measure the conductivity of each sample again in the lab using the remaining sample water in each of the red/black bottle after performing our two titrations. This remainder water was sufficient to measure the conductivity for each sample. The leftover amount of sample was poured into in a clean graduated cylinder, and to ensure the integrity of the EC reading, at least 15 mL of sample was used, therein guaranteeing that the probe would be fully emerged in the sample. The results were recorded and the sample discarded. The cylinder and electrode were cleaned with de-ionized water and allowed to dry. Cause for concern abated when the lab EC measurements fit within rational parameters.

Geospatial Information /GPS

The third component to the analysis of the Migyera Community Water Supply is the geospatial analysis used to supplement and show the outcomes from the water quality analyses and the survey analysis.

Collection of Data

Two Juno Trimble units were used to collect ground truth points in Uganda. A database of unique shapefiles was created in the field with intent of gathering geospatial data on the following points, lines and polygons:

Table 4. GPS Data Management: Field Collection

GPS Fields	Description	Shape
Household ID	Locations of households where surveys were conducted	Point
Latrine ID	Latrines associated with households where surveys were conducted	Point
Water Sources	Access points for water collection	Point
Surface Water	Public and private dams where permission was granted	Polygon
Points of Interest	Key landmarks within the Migyera Town Council and surrounding area	Point
Roads	Paved and unpaved roads, footpaths, and trails in Migyera Town Council	Line

When collecting ground truth points, an average of 9 satellites calculated a median PDOP[13] of 1.44 and an average of 6.3 meters error was achieved.

Household IDs, Latrine IDs, and Water Sources were collected during the enumerator's administration of the household surveys. The Water Sources shapefile was designed to categorize collected points into “Source” and “Point of Use”, so it was used whenever a water sample was taken, whether that sample was intended for microbial or chemical analysis.

[13] PDOP is an acronym for the positional dilution of precision, a measure of how positional error will affect the final result.

Depending on the type of sample taken, the file was designed to prompt the GPS user the following questions in the given order:

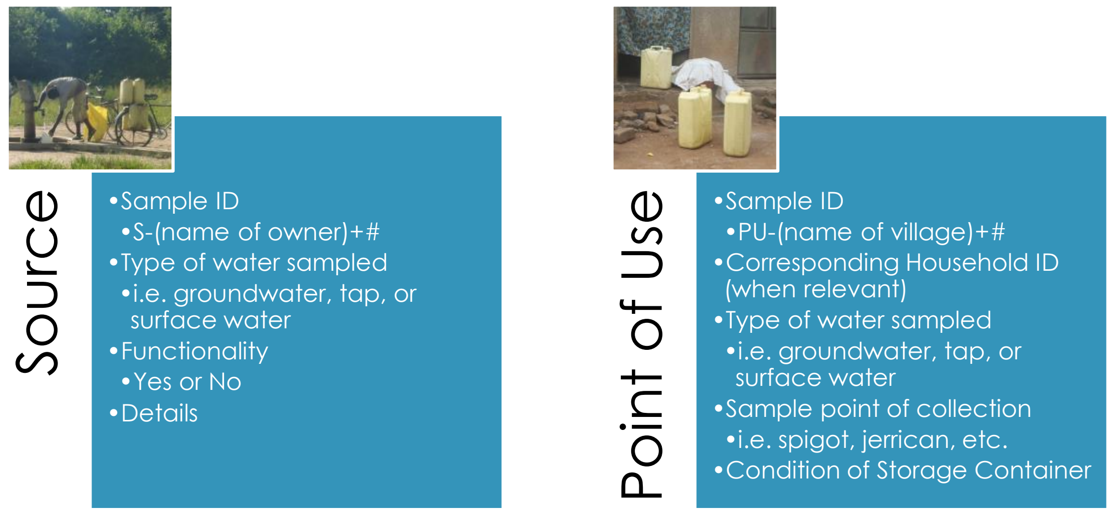

Figure 3. Water Sampling Point Collection Options

Keeping all water sampling data together made it easier to later join water quality analysis results to the points both in Excel and in ArcMap software. Surface water polygons required the circumnavigation of the perimeters of the plotted dams. The remaining data categories, especially those pertaining to Town Council infrastructure, were collected throughout the duration of the project. Many of the roads were created from data amassed by Trimble's tracklog, a feature of the GPS units that logs the location of the unit every five seconds. This allowed the team to streamline recording all of the roads in the project study area by using bodabodas to cover more area.

Design of Latrine Evaluations:

In tandem with the collection of GPS points of participating households and water samples, latrine evaluations were performed using the Trimble units. Based on two studies about the relationship between quality of latrine and disease in Eastern Africa, the evaluation design was purely based on a visual inspection performed by the Duke team. This meant that the evaluation would be more objective than if the data was self-reported by household members. On top of recording the GPS location of the participating household's primary latrine, this specific data file was designed to ask the GPS user a series of standardized questions with respect to the current state of the observed latrine. Unfortunately, given the insufficient number of GPS units, this component of the GPS data collection was given a lower priority than participating household and collected water samples locations, so less latrine evaluations were collected than surveys administered. In total, 96 latrines were visited and examined compared to the 131 household surveys administered.

Verbal consent was obtained from owners prior to observations and observations only took place in households that were already selected for survey participation. Participants were not given any forewarning of this aspect of the study as it is essential that the latrine be observed in its true state (Ross et al. 2011). Latrine evaluations were performed while the household survey was being conducted, in the absence of the owner, by a member of the Duke team. A uniform definition was selected to help Duke members determine qualifying latrines. The following definition for latrine was borrowed from a previous study based on its succinctness and appropriateness for the study area. "A pit latrine covered by either a cement slab or another appropriate locally-available material and a superstructure for privacy (not including a roof)" (Rotondo et al. 2009).

The evaluation was designed to ensure uniformity of visual observations as well as to be performed quickly. Again, building off the design described by the Rotondo et al publication, simple yes or no questions were prepared that would characterize the latrine and gain insight into the owner and user's sanitary practices and preferences (2009). The inspection criteria included: latrine construction practices, ownership, safety, use, upkeep, and preferred hygiene practices (i.e. presence of wiping materials, type of wiping materials, and existence of a hand washing station)[14] (See Figure 4 on the following page).

In addition to affirmative or negative questions, some of the criteria required assigning the latrine to a scaled response. To avoid confusion about the scales, examples of each stage were discussed among the Duke team prior to implementation in the field. Different criteria was used to explore various facets of rural Ugandan sanitation and hygiene, some of which was not entirely straightforward. For example, the questions regarding the existence of a door, lock, and the wall height were used as proxies for privacy as well as preferences.

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[14] A hand washing station was defined to be some form of small storage of water put aside near the latrine. Additionally, the presence of soap was noted.

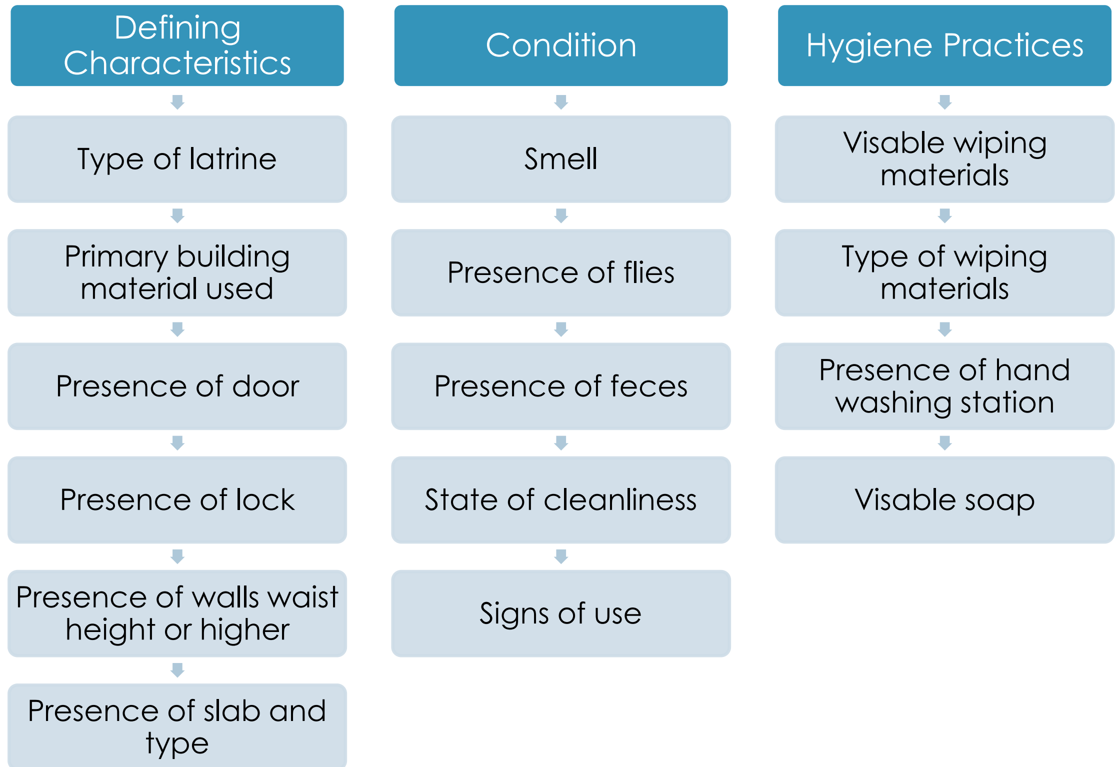

Figure 4. Latrine Analysis through Geospatial Data Collection

Challenges

One challenge we knew we were facing going into the project was our inability to geometrically correct for any spatial error in our data. This was due to the fact that there are not any base stations in Africa that our GPS units would be able to connect to in order to verify that we were actually in the location our GPS was telling us we were in. This means that we will have to accept a larger margin of error with our geospatial analysis due to the inherently greater meter inaccuracy of our data. While in Uganda this problem was further exacerbated with cloudy weather, although there were no tall buildings or trees that would cause any significant disruptions to the data collection.

Prior to departing for Uganda, we attempted to find relevant GIS files for the Migyera Town Council in order to glean some background on the area. There was limited data available for the region, available data consisting of mostly government GIS shapefiles, such as roads and sub-district boundary lines. This meant that the majority of the data collection, and eventual GIS analysis was limited as no such analysis has been done in the area before. We also discovered during the collection of data in Uganda that some of the government GIS files that we downloaded were incorrect, namely the roads. After assuming that our data collection was showing up incorrectly on the GPS units in comparison to the roads we were able to determine that the roads on the government provided file were in fact turned 90 degrees from their actual position. This uncertainty delayed collection of additional GPS data as we were attempting to correct a problem with how we were collecting our data instead on recognizing the problem with the obtained file.

While we did collect many relevant GPS points, some were excluded to the inaccessibility of the location. This mainly consisted of dams that had thick brush or sheer rock surround the edge which would have created an inaccurate polygon shape. Additionally, many of the roads and footpaths were not collected as we did not have the time to walk and collect points along every single path.

Different analyses performed in US

All data was organized and compiled into final versions, which were then analyzed using different tools in ArcGIS. Water quality analysis was added to the corresponding water sampling points and participating households. In order to explore the geospatial relationship of groundwater constituents, the Inverse Distance Weighted (IDW) interpolation method was used on all groundwater samples.

Analysis & Results

In conjunction with CALU, overarching themes were identified as basis for our analysis including: differences in water quality, collection, and treatment as a result of seasonality, and the impacts of water source and treatment as a causes of illness. These themes were translated from the three driving questions listed below, particularly questions 1 and 2.

Looking at seasonality was important to CALU as the dry season causes habitual changes in Migyera residents as well as exponential water stress on all water sources in the Town Council. For example, some sources dry up, becoming unusable and creating strain on other water sources as options become limited. This burden eventually spirals out of control, where more people end up relying on the few functioning sources until they too become exhausted.

In the same vein, looking at the prevalence of waterborne illness was equally as important to our client for the same reason, the compounding negative effect it can have on the community. For this instance, diarrhea was used to represent general water and sanitation related illnesses. Alone this indicator communicates only basic information about the actual disease burden of the community; however, when combined with personal preferences, local knowledge, and objective observation, the scope of inference is significantly broadened and we can begin to see larger connections. Using data from the household surveys, bacteriological testing, and latrine evaluations we completed the following analyses.

Respondent Demographics

Overall, we achieved a response rate of 97.7% based on household surveys completed versus households visited. Our final survey total was 132 and our previous calculations determined our necessary sample size of 124 households, accounting for a minimum of a 90% response rate. Only 2.3% of households visited refused to participate in the survey. After completion, 1 survey was excluded from our final analysis as it was uncovered at a later date that the participant was not a resident of Migyera. This survey is not included in the total numbers.

The survey protocol was designed with proportional, random sampling to accurately preserve the demographics of the community as a whole in the analysis.

Table 5 below shows the demographics of the respondents. A majority of the respondents were females with the respondent age being in the 18 – 33 year old category. This was not surprising as women typically remain in the home during the day to maintain the house and children, and moreover, most of our surveys were conducted between 2:00 – 7:00 pm. Also, it had been expressed by members of the Town Council during our meetings that Migyera has been growing rapidly. Coupled with the Ugandan life expectancy of 48.8 years for men and 52.0 years for women, we anticipated that many of our respondents would be younger.

Table 5. Demographic Variables

Variables	Measurement	Number (%)
Household Participation	Yes	128 (97.7)
	No	3 (2.3)
Respondent Gender	Male	33(26)
	Female	95 (74)
Respondent Age	<18	5 (3.9)
	18 – 33	84 (65.6)
	34 – 49	25 (19.5)
	50 – 65	8 (6.3)
	>65	6 (4.7)
Religion	Muslim	24 (19)
	Christian-Orthodox	11 (9)
	Christian-Protestant	45 (35)
	Christian-Catholic	32 (25)
	Other	15 (12)
Tribe	Baganda	35 (27)
	Baluri	51 (40)
	Banyankole	14 (11)
	Bunyoro	9 (7)
	Other	19 (15)
Language	Luganda	115 (90)
	Luluri	54 (42)
	Lunyankore	13 (10)
	Other	22 (17)
Household Size	1-3	39 (30.5)
	4-6	55 (43)
	>6	34 (26.6)

Uganda is a religiously diverse country with the 2002 Ugandan census reporting 33% of the population as Roman Catholic, 33% as Protestant and 16% as Muslim. In Migyera, we found that most people identify themselves as Protestant Christians, with 35% followed with Catholics at 25% then Muslim at 19%. When self-identified as other, this was either a Born Again Christian or Seventh Day Adventist, which was not included in the original survey options. Every household who participated in the survey identified with some religious affiliation, similar to the Ugandan census where less than 1% of respondents did not identify as religious. The varied religious backgrounds in the community was expected due to our prior information on Uganda's demographic make-up and is important to note as many religions, especially Islam, have different sanitation standards dependent upon their religious beliefs.

Another area with a great deal of diversity was tribal affiliations and languages of our respondents. To clarify, for these questions, we asked the respondents to include all tribes and languages affiliated with any household members currently residing in the house. While every households only associated themselves with one tribe, most households spoke several of the Ugandan dialects. This accounts for the discrepancy of the large proportion of households that consider themselves to be in Baluri tribe at 40%, but only 27% of the households speak Luluri, the dialect associated with the Baluri tribe. As the households speak multiple languages, Luganda was the primary dialect, with 56% of the households using it.

There was also variation in the number of people within each household, with the majority of households containing 4 – 6 members. According to our meetings with the Migyera Town

Council, we were expecting slightly larger households, containing an average of six household members, which was the number used in estimating our sample size. In reality, the young population is reflected in the household size, as many new families are forming. We anticipate that the household size will increase as the population age increases.

Water Quality

Many factors including chemical, physical and biological characteristics contribute to the overall water quality in an area. Therefore, this section will cover all of the components that play into the overall water quality including the variables involved in water quality such as bacteriological and chemical contamination, water collection, management, storage, and treatment strategies, and the importance of seasonality in both of these aspects. In particular, this sections addresses the first and second driving question as outlined above.

> 1. *What are all the accessible water sources in Migyera Town Council and what are their contamination levels?*

Chemical

Different chemical constituents were examined as described in the methods section. While all the samples were run in the machine together, the origin of the sample source remains important to deciphering the results and will be presented in a manner that distinguishes them from one another. The conditions under which the samples were taken should also be noted. Given the depth of the water table in the region, there were comparably fewer deep borehole wells in the vicinity of Migyera Town Council than originally anticipated. In the end, samples were only taken from a total of 10 boreholes, 4 of which fell outside of the Town Council borders; however, some boreholes were visited more than once. If sampled more than once, follow up sampling usually took place a month or more after the first visit.

The reasoning behind this technique was to capture the seasonal variability in the water quality as the rainy season ended and the dry season began[15]. Surface water samples were also collected with this rationale in mind, with one sample having been collected immediately after a

[15] To truly capture the seasonality, a time-series testing procedure would be required and is encouraged by the authors of this report.

significant rainstorm and another after several days without precipitation. When it came to rainwater and tap water samples, collection was more opportunistic given the unreliability of both sources. Both rainwater samples came from a single precipitation event in which clean plastic basins were left in the open air. These samples had no interaction with roofs, gutters, or storage containers. This method was initially chosen to preserve certain isotopes for future analysis, but that level of analysis proved to be outside the project's scope. Fortuitously, these rainwater samples acted similarly to our bacteriological negatives, in that they tested the precision of our findings and they added variety to our results.

Source Characteristics

In analyzing the water source samples for a total of 35 constituents, much was learned about the nature of the different sources of water, each of which will be discussed separately. Understanding what primary chemical components influence the water sources allows us to better predict how that water will act in certain situations and under certain conditions, which is essential to beginning to establish an integrated water resources management plan.

Table 6. Chemical Water Sample Average Parameters

Variable	*Obs*	*Mean*	*Std. Dev.*	*Min*	*Max*
	Groundwater (GW)				
EC(uS/cm)	19	327.189	168.641	0.567	525.7
pH	19	7.759	0.216	7.23	8.2
Alkalinity(HCO3)	19	246.957	76.191	156.630	388.597
TDS(mg/L)	19	379.804	119.035	248.652	650.978
	Surface Water (SW)				
EC(uS/cm)	4	101.15	10.1671	90.1	114.7
pH	4	6.783	0.367	6.25	7.09
Alkalinity(HCO3)	4	51.030	4.171	47.945	56.956
TDS(mg/L)	4	76.766	7.580	71.765	88.027
	Rainwater (RW)				
EC(uS/cm)	2	44.3	46.103	11.7	76.9
pH	2	5.785	1.435	4.77	6.8
Alkalinity(HCO3)	2	19.728	26.533	0.967	38.490
TDS(mg/L)	2	31.556	15.511	20.588	42.524

The basic statistics for the three types of sources are given in the table above. Groundwater stood apart as having the highest average electrical conductivity (EC), which is a measure of a water's ability to conduct an electric current, as well as the largest range. With respect to pH, rainwater was significantly more acidic than the other two sources; however, it also had the largest range and the least observations. Groundwater was found to be more basic than surface water. The capacity of water to neutralize acids is measured via alkalinity, which was determined by calculating the quantity of bicarbonates (HCO_3) in the sample. Of the three sample sources, rainwater has the lowest Total Dissolved Solids (TDS) measurement, which indicates that it has the least mobile charged ions dissolved in the sample. TDS is also a good indicator of water salinity. All samples show TDS ranges that are consistent with fresh water. The levels found in the groundwater is consistent with the depth of the boreholes samples.

Groundwater

Extensive chemical analysis of the 18 collected groundwater samples yielded a very comprehensive glimpse of the superficial water chemistry during the wet season. While mentioned briefly above, initial field measurements and basic lab tests indicated a general presence of fresh water[16]; however, given the complexity of the geology-hydrology relationship in the area, salinity was examined more closely, looking at specific ions.

General Chemistry

Especially in the case of the groundwater, chloride (Cl) can be used as an indicator for different anthropocentric and naturally occurring processes given its hydrochemical conservative nature and its universal presence. Sodium (Na) can be used as a measure of salinity. Together, the Na/Cl ratio can hint at the source of salinity.

Table 7. Groundwater Chemistry Indicators

	EC (uS/cm)	pH (pH)	Alkalinity (HCO_3)	TDS (mg/L)	Reaction Error DCP (% DCP)	Reaction Error ICPMS (% ICPMS)
Waluk BH	476.80	7.90	277.74	411.99	-2.48%	-1.34%
Kitwe BH	522.40	7.47	193.55	377.74	-5.10%	-6.03%
CALU	487.15	7.95	317.97	441.21	-2.97%	-4.51%
Muslim	378.30	7.80	245.85	329.46	-5.35%	-5.58%
Kyakala BH	311.70	7.69	178.39	262.63	-0.98%	-5.08%
Kyamu	0.57	8.20	388.60	519.86	-2.68%	-5.15%
Town Council	362.10	7.66	236.72	320.36	-2.92%	-2.09%
Kyab BH	322.73	7.72	159.13	263.31	-1.88%	-3.19%
Nabiswera	484.00	7.90	242.77	396.33	-1.90%	-2.56%
Walusi	0.71	7.76	357.48	633.61	-1.72%	-5.69%
UWESO	288.20	7.59	171.89	248.65	-7.39%	-5.84%

[16] This is what would be defined as potable water or the opposite of salt laden brackish water.

Na/Cl Ratio for All Processed Chemical Samples

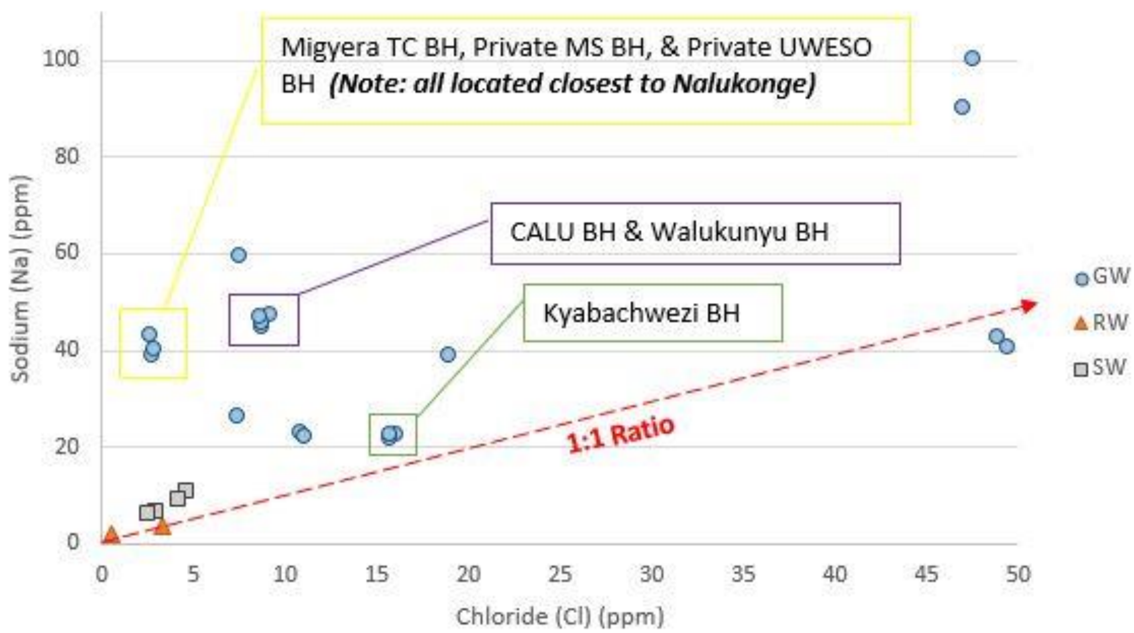

Figure 5. Sodium/Chloride Ratio for Chemical Water Samples

Typically, anthropogenic salts have higher sodium than chloride, so a Na/Cl ratio greater than 1 can be used as a geochemical indicator of potential sewage contamination. However, this ratio can also occur naturally where certain combinations of water and rock exist together and interact[17]. As can be seen in the figure above, most groundwater samples and all surface water samples have ratios that exceed this ratio. Given the geologic makeup of the region, the relatively sparse human population, and the corresponding geochemical results, it seems unlikely that higher levels of sodium would be caused by anthropogenic activities. It is more probable that the Na is released from silicate weathering reaction, essentially water-rock interaction (Krishnaraj et al. 2011).

Similarities in samples have been highlighted in Figure 5 in an effort to show the general consistency of the chemical composition of the wells tested and to call out some more interesting relationships. The color purple is used to draw attention to the similarities in the Na and Cl levels between the CALU borehole and the Walukunya borehole, more than 6 kilometers away, whereas the Kyabachwezi borehole is located less than a half a mile away from the CALU borehole. This suggests that these two boreholes may be on the same natural

[17] More specifically, this typically occurs where bedrock containing feldspar minerals comes into contact with carbonate acid, created when CO2 is dissolved in water, in the groundwater, causing weathering (Krishnaraj et al. 2011).

groundwater flow path, connected within a fractured aquifer. For this geographical location it potentially means that both boreholes are drawing from the same fractured aquifer in the area. Aside for chemical concerns, water availability to these wells may be an issue in the future.

Calcium (Ca) and Magnesium (Mg) are very mobile cations, which are present in the tested samples. These ions move freely with water through soils, weathered regolith, and fractured bedrock. A majority of the water samples were found to have Ca/Mg molar ratios less than or equal to 1, which indicates that groundwater is involved with the natural breakdown of rocks that contain mineral deposits of Ca (calcite) and Mg (dolomite). More specifically stated, this ratio suggests that dissolution of dolomite and calcite might be the dominant geochemical processes at work in the study area for some of these samples (Edmunds 2008).

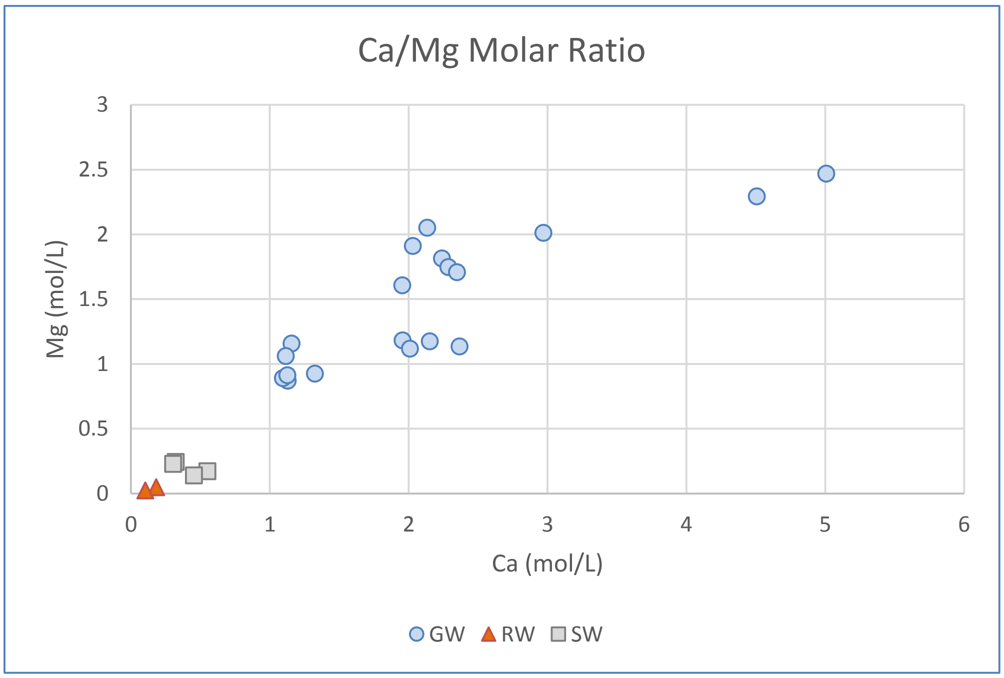

Figure 6. Calcium/Magnesium Relationship in Chemical Water Samples

In approaching this chemical analysis, we were looking for signs of the following forms of pollution: salinity, wastewater, agriculture, trace metals, and radionuclides. Generally, elements of concern were typically trace metals that are known to have a negative impact on public human health. For most of these constituents, the duration of the exposure to substantial amounts of any of these natural elements and quantity ingested presents itself as distinct physical manifestations. Arsenic, fluoride, lead, and uranium were the constituents identified.

Arsenic

Found all over the world, arsenic is a naturally occurring semi-metal element that is found deposited deep in the earth's surface, i.e. bedrock. Colorless and tasteless, consuming significant quantities over long periods of time leads to arsenicosis, an advanced state of arsenic poisoning. Typically, initial symptoms present as skin lesions, predominantly on the hands, bottoms of feet, and mouth. In the long term, exposure to arsenic via drinking water can significantly increase the risk of developing cancer (Klaassen and Watkins 1998).

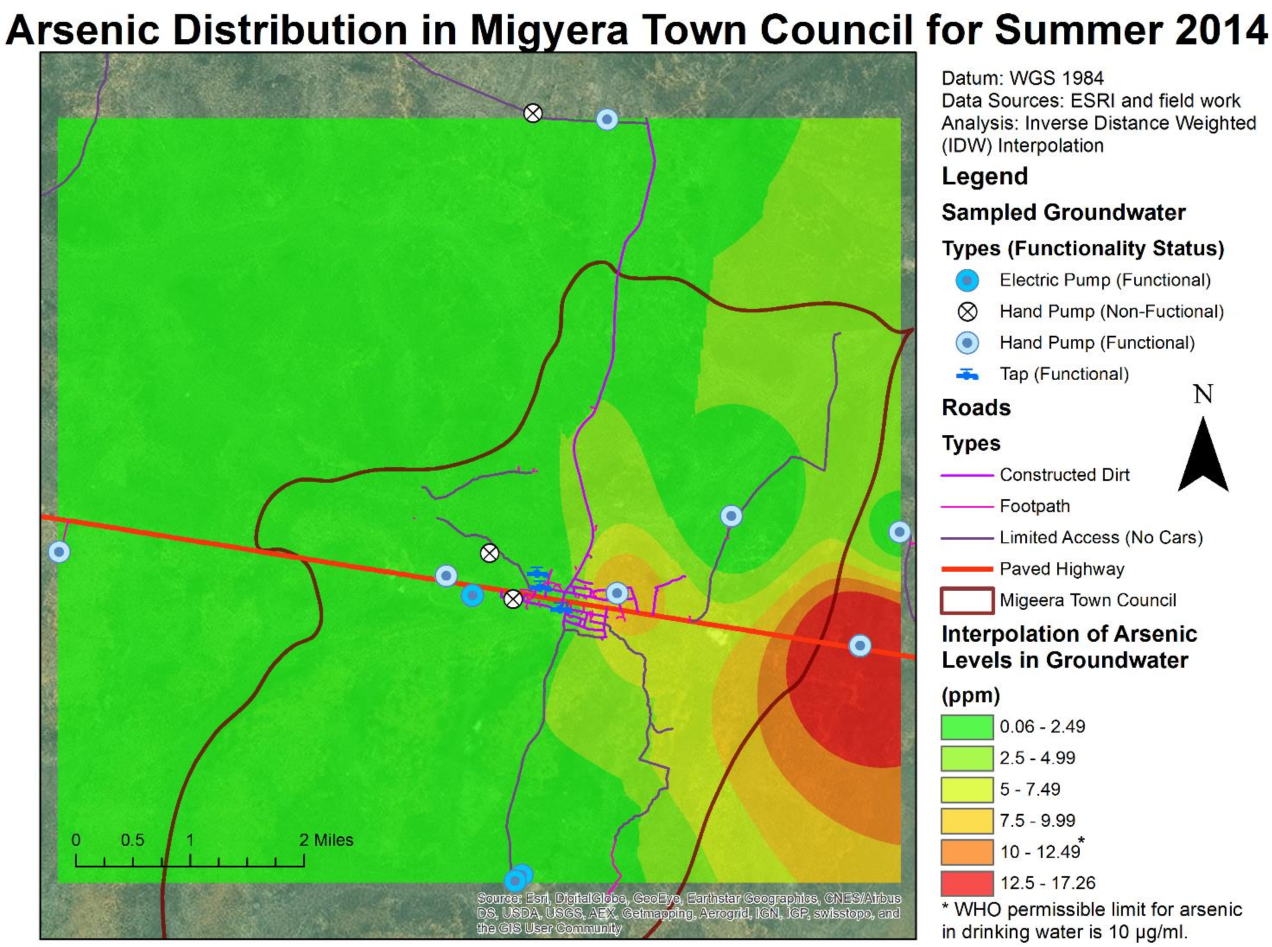

Figure 7. Arsenic Interpolation in Migyera Town Council

Geospatial interpolation shows arsenic distribution from the center of the Town Council, in Kitwe Kyambogo, and east along the highway in Walusi. Located immediately east and outside the Town Council, the borehole in which the most arsenic (0.0257 ppm) was located in Walusi. The quantity of arsenic measured greatly exceeds the WHO primary limit of 0.01 ppm (WHO 2011). The given graph shows two points near the WHO and the Ugandan drinking water exceedance values. These points are from the same borehole in Kitwe Kyambogo, but represent samples taken during different months. Over the course of a month, from June to July, this particular borehole had a 0.00018 ppm increase in arsenic, potentially caused by the slow depletion of groundwater reserves.

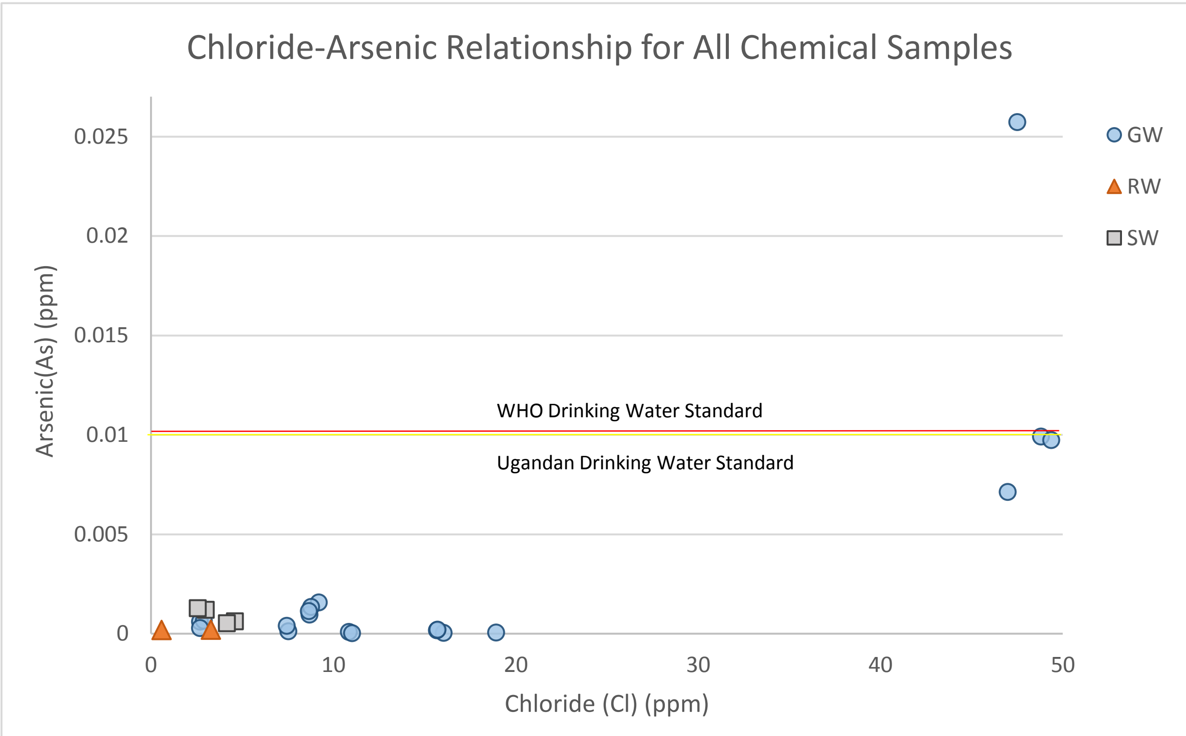

Figure 8. Chloride/Arsenic Relationship in Chemical Water Samples

Fluoride

Despite common belief, the presence of fluoride in groundwater is a complicated public health problem. Often described as a "double-edged sword"; while too much (>1.5 ppm) can cause detrimental health consequences (dental and skeletal fluorosis), too little results in dental decay and mineralized bones (0.1 – 0.3 ppm) (Klaassen and Watkins 1998). Excessive ingestion of fluoride can cause dental fluorosis, resulting in discoloration, spotting or streaking of the tooth surface, and break down of the natural enamel. In extreme cases, there is yellow or brown staining and pitting of teeth. The staining takes place while the teeth are growing in the jawbone and under the gums, which indicates that the manifestation is dependent on the dose, length of exposure, and age at exposure (Jha et al. 2011). The development of skeletal fluorosis happens in children and adults. It involves the gradual increase in bone mass and density and, in most cases, entails the regular consumption of extremely high doses of fluoride for nearly a decade (Jha et al. 2013). It presents symptoms similar to arthritis, beginning with the stiffening and aching of the major joints due to large deposits of fluoride that make it inhibit mobility (Jha et al. 2011).

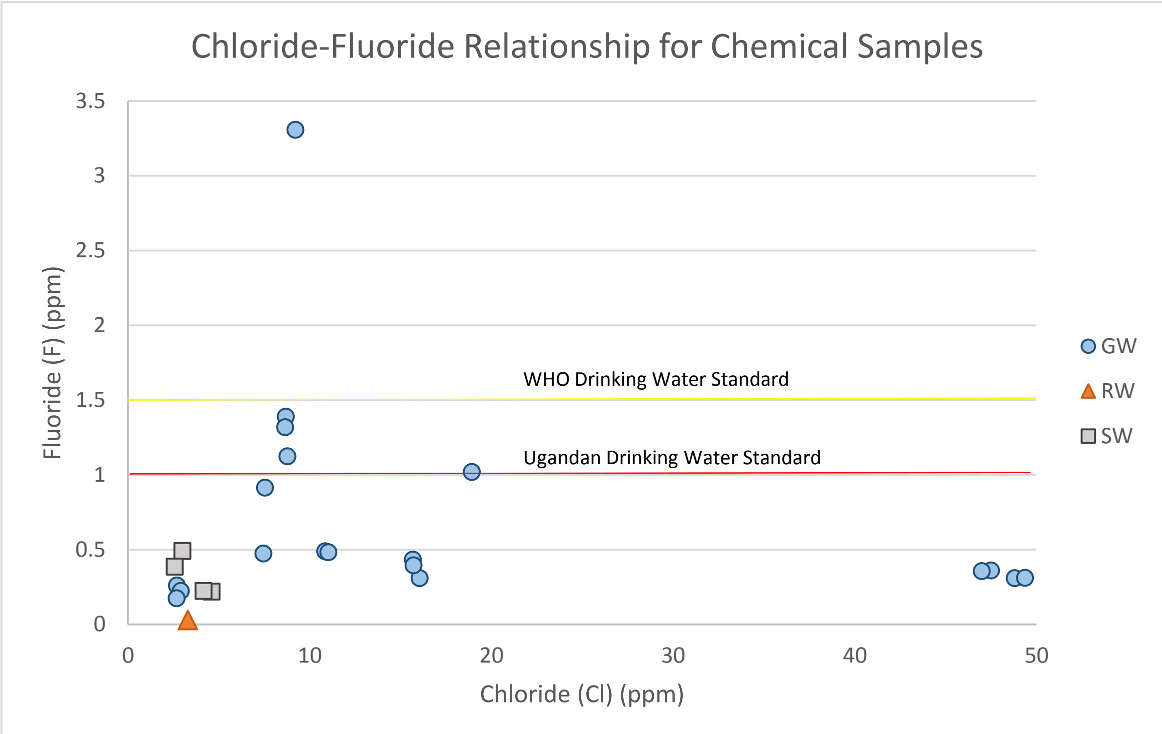

Figure 9. Chloride/Fluoride Relationship in Chemical Water Samples

As hypothesized, there was at least one instance in which a borehole was found to have levels of fluoride above the WHO drinking water standard of 1.5 ppm (WHO 2011). However, this sample was taken from a borehole in Walukunyu, a village to the east and outside of Migyera Town Council. It contained twice the amount of fluoride suggested by the WHO and three times the limit set by the government of Uganda. Interestingly, and not visible in the map below, the fluoride contaminated borehole is located a mere 10 meters adjacent to the village's decommissioned former well.

Analysis showed some boreholes within the town council were borderline with respect to the quantity of fluoride measured, including the CALU borehole. Zooming in on CALU headquarters, the map shows two yellow circles, one borehole and its corresponding on-site tap. Sampled in both June and July, results showed a small decrease in the CALU borehole's fluoride content (1.32–1.13 ppm). While seemingly insignificant, this slight fluctuation confirms the characteristic dynamic nature of the groundwater given the aquifer's fractured system and pronounced seasonality.

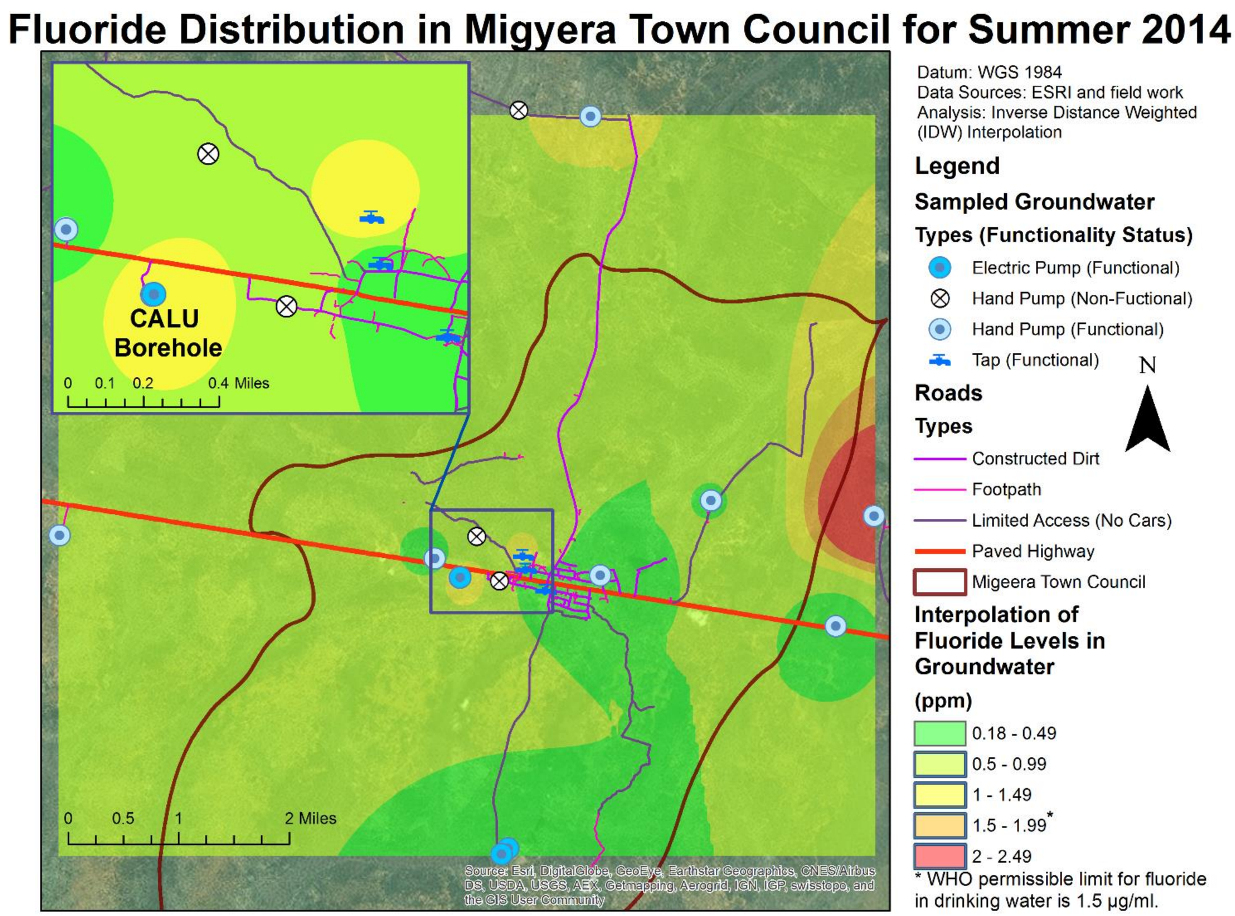

Figure 10. Fluoride Interpolation in Migyera Town Council

Fluoride appears to have a positive relationship with sodium, as can be seen in the trend line included in Figure 11 on the right. Supporting this finding, multiple geochemical investigations have shown fluoride concentration in groundwater is positively correlated with salinity, sodium, and bicarbonate

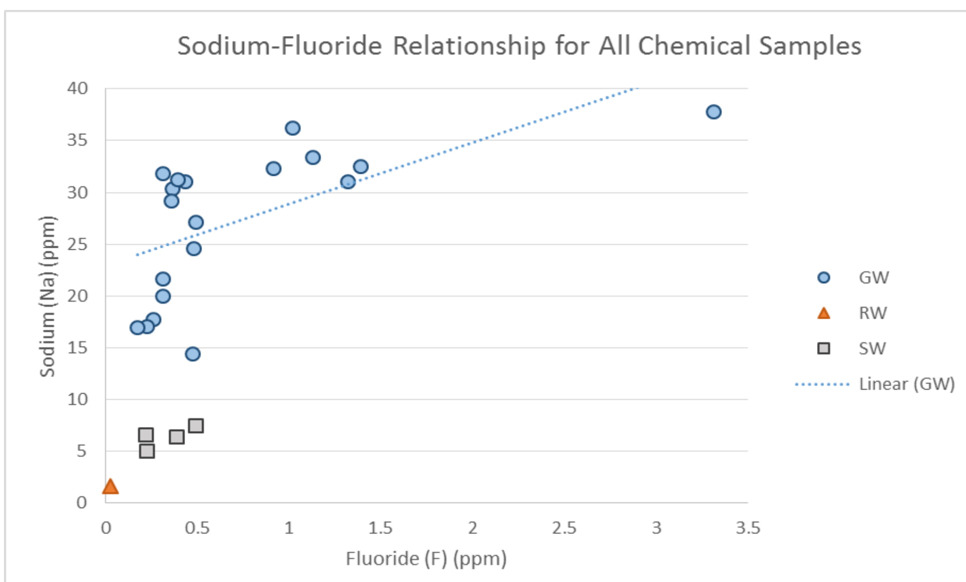

Figure 11. Sodium/Fluoride Relationship in Chemical Water Samples

and negatively correlated with calcium (Rango et al. 2012).

Uranium

One of the most surprising chemical findings, although consistent with previous studies performed in geologically similar locations, was the significant presence of uranium found in the Kyamukanda borehole. Uncertainty still remains around the actual toxicological effects of uranium on humans. While its carcinogenic properties are still contested, it has been proven to cause renal failure at high doses. This sample surpassed the WHO limit of 0.03 ppm (WHO 2011). All other samples were found to fall well below this upper bound.

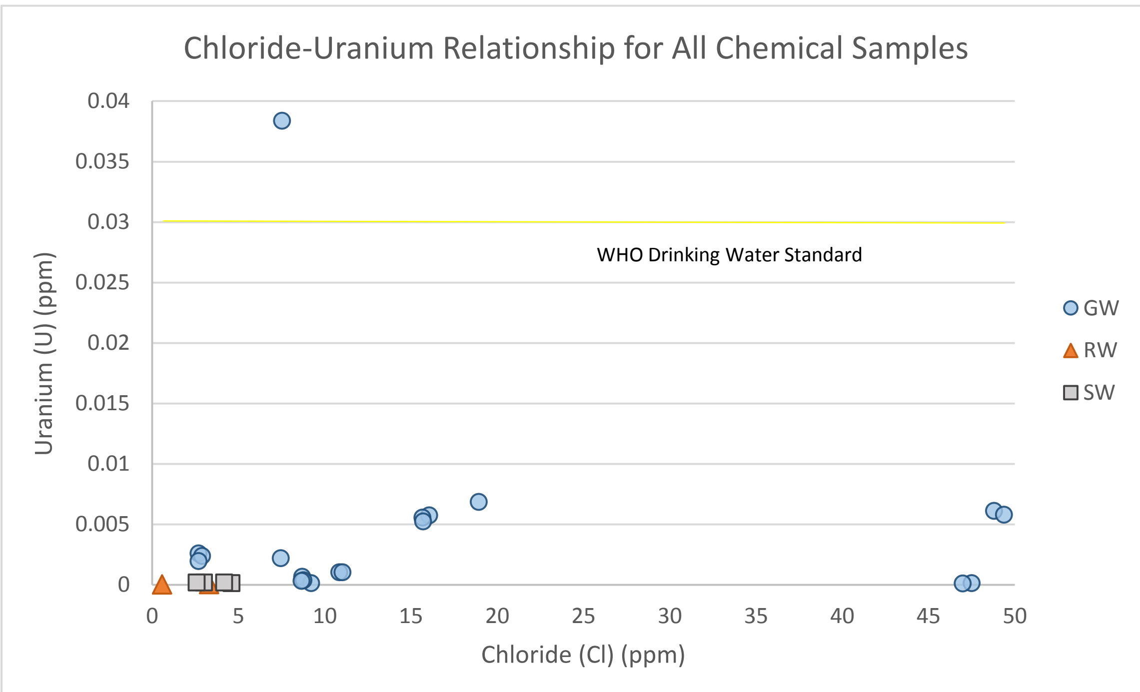

Figure 12. Chloride/Uranium Relationship in Chemical Samples

Finally, a substantial spike in lead was detected in the second sample of a town council tap. This water sample originated from the spigot outside of the Fathers' private residence, which only received water twice during the two and a half month study. According to the Fathers, irregularity of service has existed since the tap's installation. The location of this tap, towards the outskirts of Migeera A, makes it one of the last recipients on the distribution scheme. Upon examination, the tap was always kept open, in the event that there was enough pressure to carry the water or a surplus of water. The water meter was broken and the tap sat adjacent to another rusty and padlocked decommissioned tap.

The context of this source does a lot to explain the how this sample had 0.0186 ppm of lead, when the WHO guidelines are set at 0.01 ppm (WHO 2011). The water originated from the Town Council borehole in Nakasongola and similar levels of lead were not found in either the Town Council or adjacent UWESO boreholes. The last time the tap had functioned was nearly a month prior to the sample being taken. These facts suggest that the water collected for the sample might have had at least a month of residence time in the town council's distribution pipe infrastructure. Given all of these observations, there is high likelihood that the lead may have come from the pipes; however, more sampling would need to be done to definitively answer this question.

Surface Water

The most prominent characteristic among surface water was high turbidity. The four surface water samples were taken from two different dams, one in June and one in July. Chemical analysis found significant quantities of aluminum and rubidium in these dam samples.

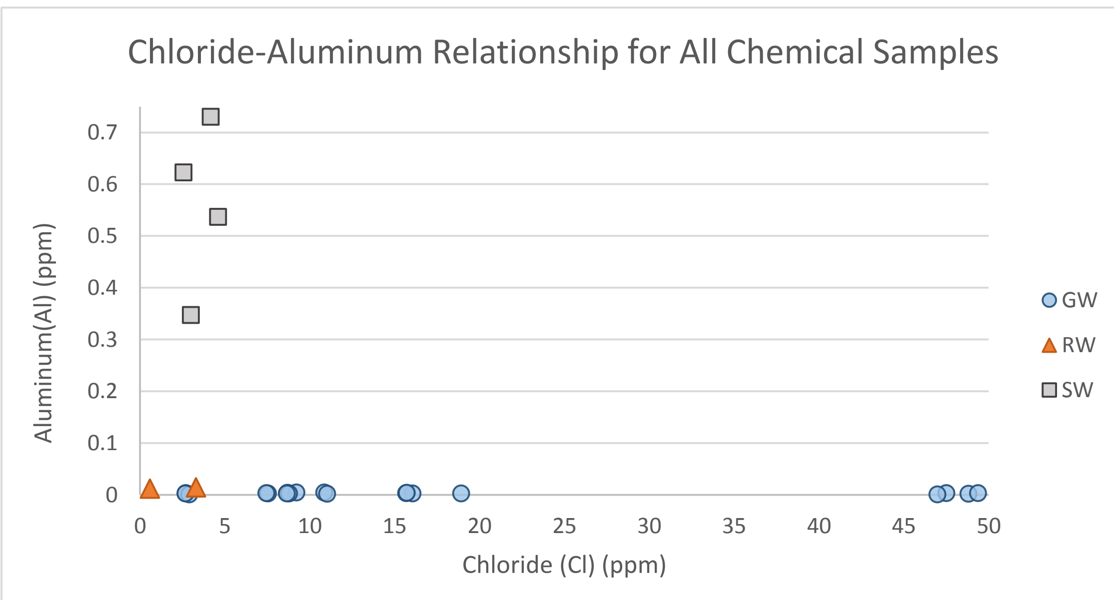

Figure 13. Chloride/Aluminum Relationship in Chemical Water Samples

High levels of these two constituents suggest that there was a filtration issue during sample collection in the field because neither typically dissolves well in water. Additionally, this error was observed in all four surface water samples and each dam showed consistent quantities over the two month collection period. Concern about these dam water samples was raised in the field given the number of filters required to prepare the usual sample kit. At the time, the filtration issue was attributed to the high turbidity of the sources and large quantity of organic materials present. Given the proven characteristics of these constituents and the data, it is likely that the detected impurities are coming from the solids in the water, most likely the alluvial sediments of the dams. While the data from these samples do not accurately represent the levels present in the sampled waterbodies, it does indicate that a commonly used water source is not safe for human consumption.

Even with the use of laboratory grade filters on the water, excessively high levels of these trace metals still persist, suggesting that the use of natural filtration is probably not an effective treatment method. As a result, consuming dam water for drinking means exposure to metals derived from suspended matter in the dam water such as Al and Rb.[18]

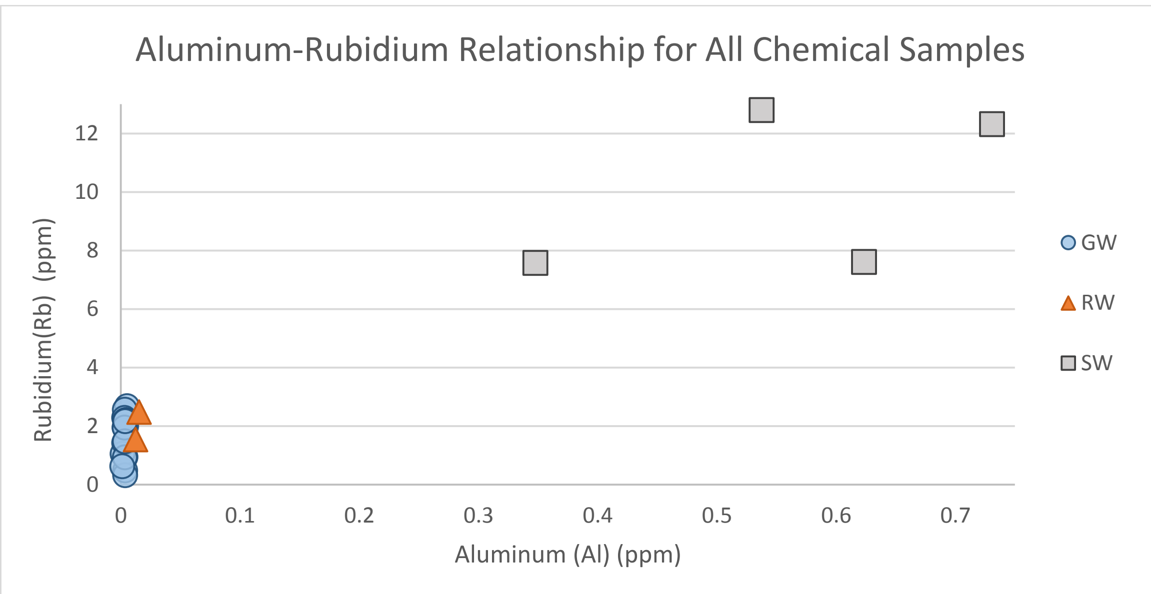

Figure 14. Aluminum/Rubidium Relationship in Chemical Water Samples

Rainwater

Given that our rainwater samples were taken as controls, our results did not yield any conclusive findings about this source. As expected, the rainwater showed generally low levels of constituents. An interesting finding was that the rainwater results had the highest amount of testing equipment inaccuracy, which could have been due to the measurements being extremely close to the machines' detection limits. Overall, the lack of findings validate our general conclusion that most contamination occurs when water comes into contact with people and the earth.

[18] Upon reflection, a feasible hypothesis for the origins of the suspended rubidium is the usage of two-mica granite, a type of granite with high mica content, as construction material for a majority of local roads.

Table 8. Quality of Chemical Testing Results

LABID	HHID	Type	Sample Source	Description	Source Sample Number	Date Taken	Reaction Error % DCP	Reaction Error % ICPMS
1	S-WALU002	GW	Hand pump	Walusi BH	1	12-Jul	3%	-3.99%
2	CALUTAP001	GW	Tap	CALU new tap	2	4-Jul	-2%	-6.43%
3	S-MIGA002	SW	Dam	MIGA Dam 2	2	9-Jul	-7%	-10.72%
4	S-WALUK001	GW	Hand pump	Walukunyu BH	1	12-Jul	-2%	-1.34%
5	S-RW001	RW	RW	Rainwater	1	8-Jul	-0.42%	-2.79%
6	S-KWI001	GW	Hand pump	Kitwe Kyambogo BH	1	19-Jun	-4.33%	-5.64%
7	BHCAL002	GW	Main	CALU (+2 pump)	3	7-Jul	-3%	-5.43%
8	S-KYAK006	GW	Hand pump	Kyakala BH 2	2	10-Jul	2%	-3.89%
9	S-UWESO001	GW	Main	TC BH @ UWESO	1	1-Jul	-3%	-2.09%
10	S-MSTAP	GW	Tap	Muslim School BH	1	10-Jul	-5%	-5.58%
11	S-KYAK005	SW	Dam	Kyakala Dam	1	10-Jul	-4.62%	-9.83%
12	S-KYAK001	GW	Hand pump	Kyakala BH	1	23-Jun	-3.59%	-6.26%
13	S-KYAM001	GW	Hand pump	Kyamukanda BH	1	11-Jul	-2.68%	-5.15%
14	S-MIG001	SW	Dam	MIGA Dam	1	28-May	-8.43%	-11.40%
15	S-KYAB001	GW	Hand pump	Kyab BH	1	19-Jun	-1.05%	-2.27%
16	S-RW002	RW	RW	Rainwater 2	2	13-Jul	-62.56%	-61.81%
17	S-NAL001	GW	Main	UWESO private BH	1	23-Jun	-7.39%	-5.84%
18	S-UWESOTAP002	GW	Tap	Tap outside FP	1	13-Jul	-2.71%	-3.64%
19	S-KYAB002	GW	Hand pump	Kyab BH	2	4-Jul	-2.33%	-2.44%
20	S-KYAB003	GW	Hand pump	Kyab BH	3	7-Jul	-2.25%	-4.88%
21	S-MIGB010	GW	Main	CALU BH	1	28-Jun	-2.93%	-3.58%
22	S-NAB001	GW	Hand pump	Nabiswera BH	1	9-Jul	-1.90%	-2.56%
23	S-KYAK002	SW	Dam	Kyakala Dam 2	2	3-Jul	-9.12%	-11.01%
24	S-WAL001	GW	Hand pump	Walusi BH	1	12-Jul	-6%	-7.40%
25	S-KIT003	GW	Hand pump	Kitwe Kyambogo BH 2	2	8-Jul	-6%	-6.42%

SW = Surface Water   GW = Groundwater   RW = Rainwater

Bacteriological

The second portion of our water quality testing consisted of bacteriological testing of both water sources and point of use sources. In keeping with our protocol, a water source site continued to be considered as any place from which water originates or is collected from (i.e. dam, borehole), whereas a water point of use (POU) site is the location where the water is consumed or used, in this case at individual households. This distinction was key to our investigation and sampling protocol for collecting samples from both water sources and POUs drinking water. In evaluating the quantity of thermotolerant colonies, our biological water contamination indicator, in both types of sample we were able to better identify where the contamination occurred. The presence of fecal coliform in a source sample indicated that all water drawn from that location would contain a similar amount of coliforms, while presence in a POU sample indicates that the microbes were introduced at some point after collection. It should be noted that the acceptable total fecal coliform colony count for a 100 ml samples is 0, as set out by the WHO drinking water guidelines (2011).

Being able to make this distinction directly influenced the subsequent recommendations. Contamination of the source implies poor planning and maintenance of the extraction site and it affects the community equally. Point of use contamination suggests a more localized and individual water management problem, which is occurring somewhere in between the source and consumption or use in the residence.

In collecting these water samples, the differences between sources became very apparent. Surface water exhibited a much higher level of turbidity, the suspension of particulate and organic matter in water, than compared to other water sources, namely boreholes. Initial observations were made in the field about the positive relationship between turbidity and quantity of thermotolerant coliform colonies in the water samples; on the contrary, analysis illustrated that these variables are unrelated, as can be found in Figure 15 below.

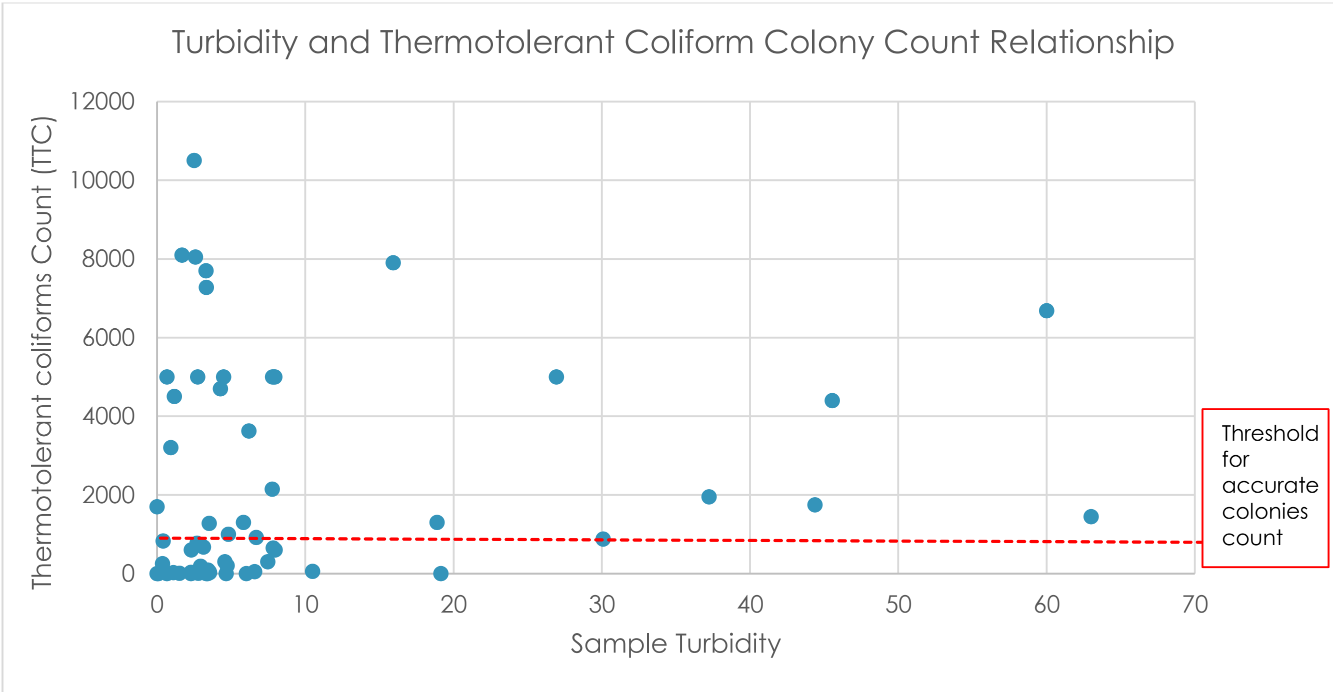

Figure 15. Relationship between Turbidity and Coliform Colony Counts

Finding no apparent correlation between turdity and microorganisms in the samples, our analysis turned to examining type of water source. Essentially, when evaluating the total fecal coliforms found in surface water, we divided the water source samples into unimproved (surface water) and improved (borehole water) and compared findings. Shown by source, the contamination results can be found below in Figure 16.

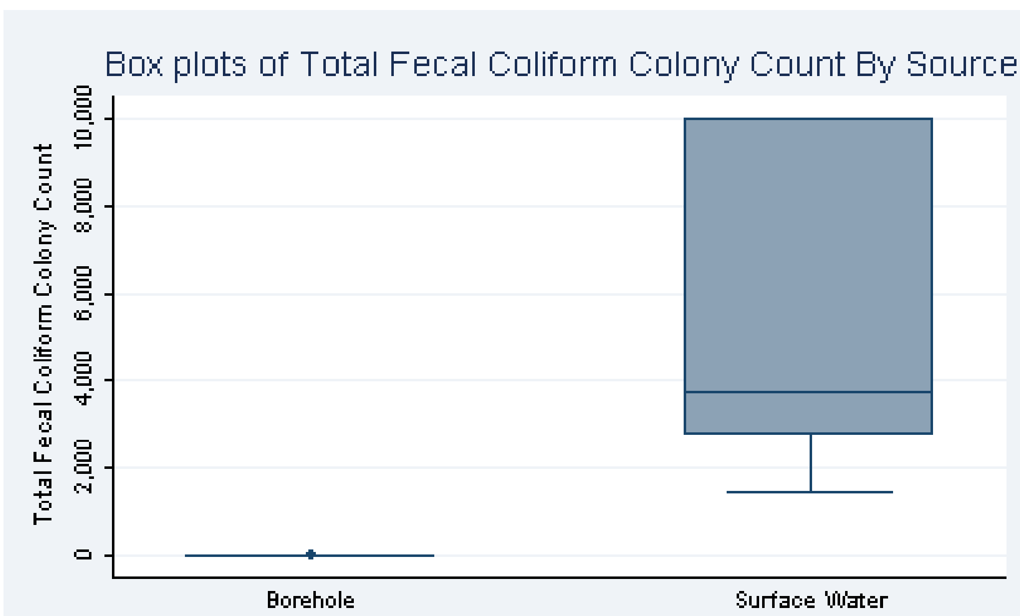

Figure 16. Total Fecal Coliform Colony Count by Water Source

The seven sampled boreholes had an average of 0 fecal coliform colonies; however, there was one outlier, the Kyakala borehole, that had 15 colonies. There are many potential explanations for this outcome, three stand out as the most feasible: 1) poor sanitary conditions at the borehole's handpump and 2) a badly sited and constructed latrine somewhere near the borehole, and 3) a fracture connecting the borehole to another part of the aquifer where there is a defective latrine. Surface water was found to be signifcantly more contaminated. All 4 samples tested positive for thermotolerant coliform with an average of approximately 3,900.

After assessing the colony counts by source, we analyzed the household total coliform colony counts. We separated the samples we took into the villages the samples were from to determine if there was a potential relationship of higher, or lower, colony counts in certain villages. Figure 17 below shows a box plot, with the dark blue line within the box representing the average colony number, for each village. As Kyangogolo and Nalukonge were smaller villages and, like the survey, bacteriological water sampling was performed as a proportional random sample, they only had one and two water samples taken, respectively.

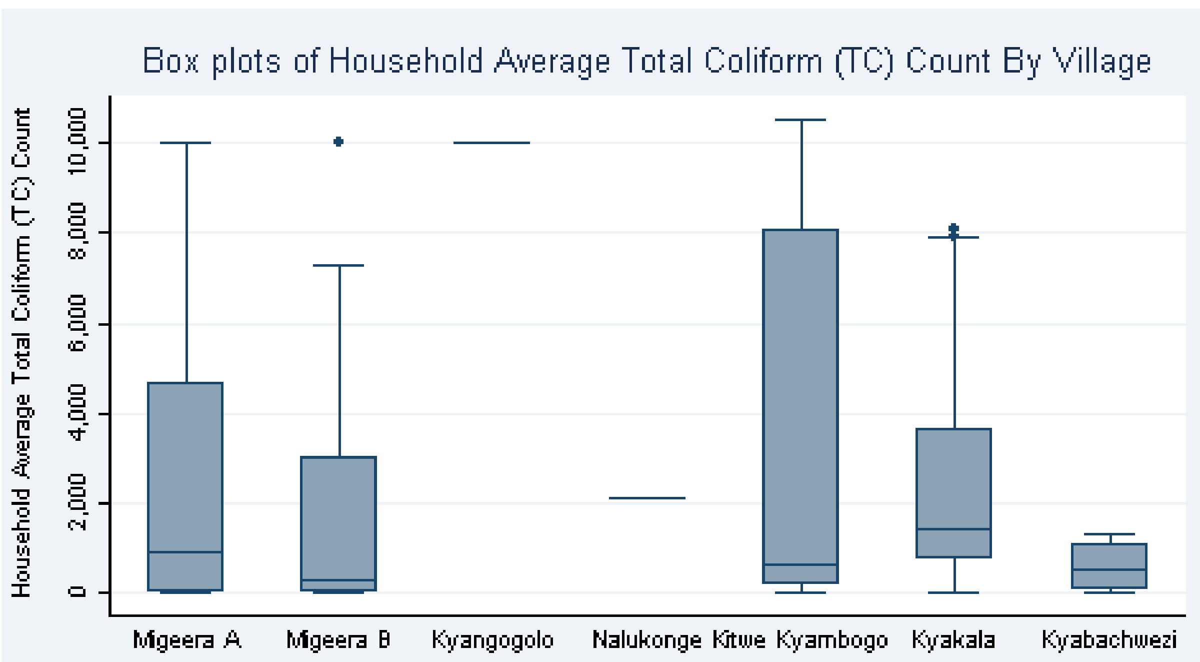

Figure 17. Average Household Total Coliform Count by Village

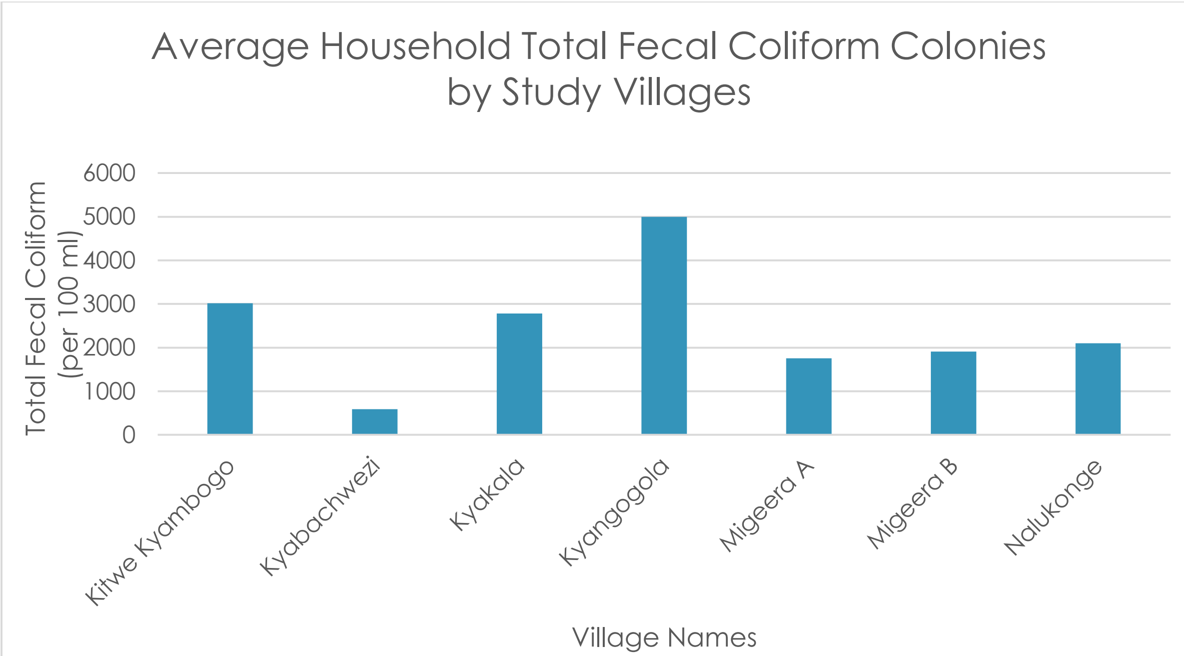

Figure 18. Average Household Total Fecal Coliform Colonies (per Village)

Figure 18, as seen above, shows an alternate depiction of the average total fecal coliform colonies found at the household level per village. When only looking at the average, and not the range of contamination, Kyangogolo looks to have the greatest contamination. However, as Kyangogolo only had one water sample taken from the village, it may be an outlier and not fully representative of the household contamination levels within the village.

2. How do households collect, store, and treat their water supply?

Collection Methods

Water collection is of significance to the community because of the time and energy that is devoted to collecting water on a daily basis. Few households have a faucet attached directly to their home, requiring the majority of citizens to collect the water themselves, or hire someone to bring the water to their home. Those that do have faucets or taps attached to their homes or nearby also have to rely on other water sources as taps and faucets are not capable of providing water all the time. As discussed, there are many different options available for water and often different sources serve different purposes within a given household. Additionally, due to the seasonality experienced in Migyera, most households switch their primary water and drinking water source between the wet and dry seasons due to the varying availability.

Figure 19 and Figure 20 below show how preferences in water sources change depending on the season. Note that Figure 19 is representative of the source of water used for all household purposes including cooking, cleaning, etc, while Figure 20 only shows the source of water that a household uses for their personal consumption. Regardless, in both figures, it is clear that capturing rainwater is the primary water and drinking water source for people during the wet season. However, in the dry season, although most people use dam water for their general use, drinking water is collected at the borehole with dam water coming in second.

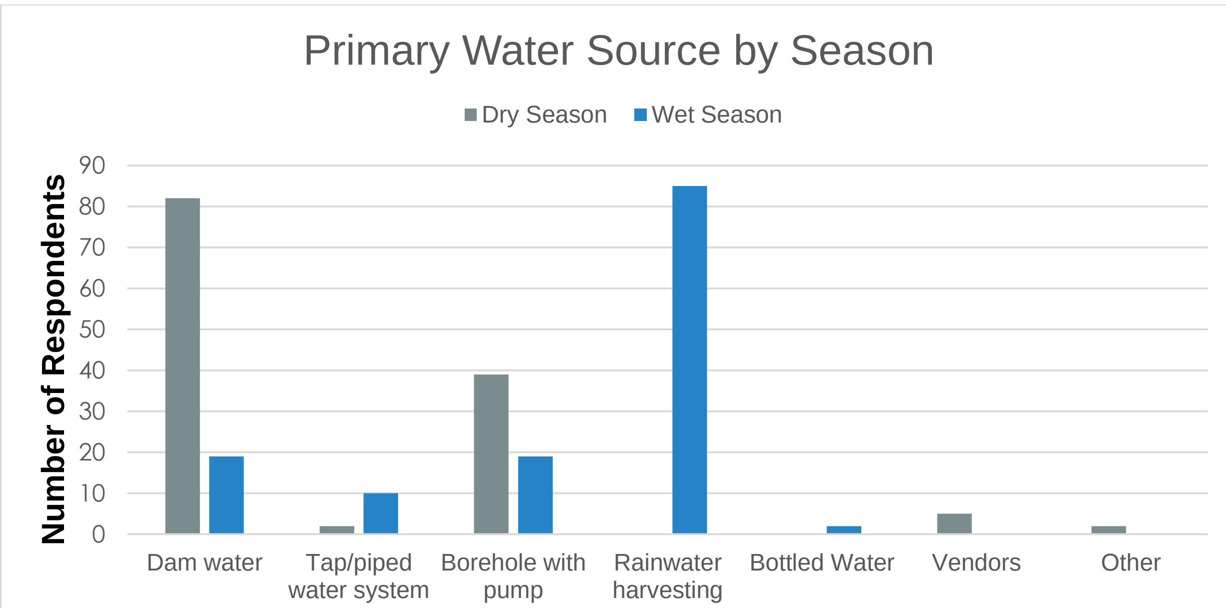

Figure 19. Primary Household Water Source per Season

Evaluating the sources throughout the season, it is clear that rainwater harvesting, dam water and borehole water constitute a majority of the water used by individuals. Again, this was not a surprise to us as the piped system is limited, only going to small sections of Migeera A and Migeera B. Additionally, the Town Council's reservoir tank is small liters and cannot provide enough water to meet demand.

The use of rainwater, when properly captured and stored, can create positive health benefits within the community since rainwater is a type of improved water source. Other sources, such as the piped system and borehole water would also be counted as improved water sources[19].

[19] WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation established drinking water categories: http://www.wssinfo.org/definitions-methods/watsan-categories/

This means that during the dry season, 40% of the population is collecting drinking water from unimproved sources, whereas only 10% of people are collecting water from unimproved sources in the wet season. In comparison to estimates of 30% of water collection coming from unimproved sources (Factbook 2012) there are heavy constrains on the population during the dry season when rainwater harvesting is not an option.

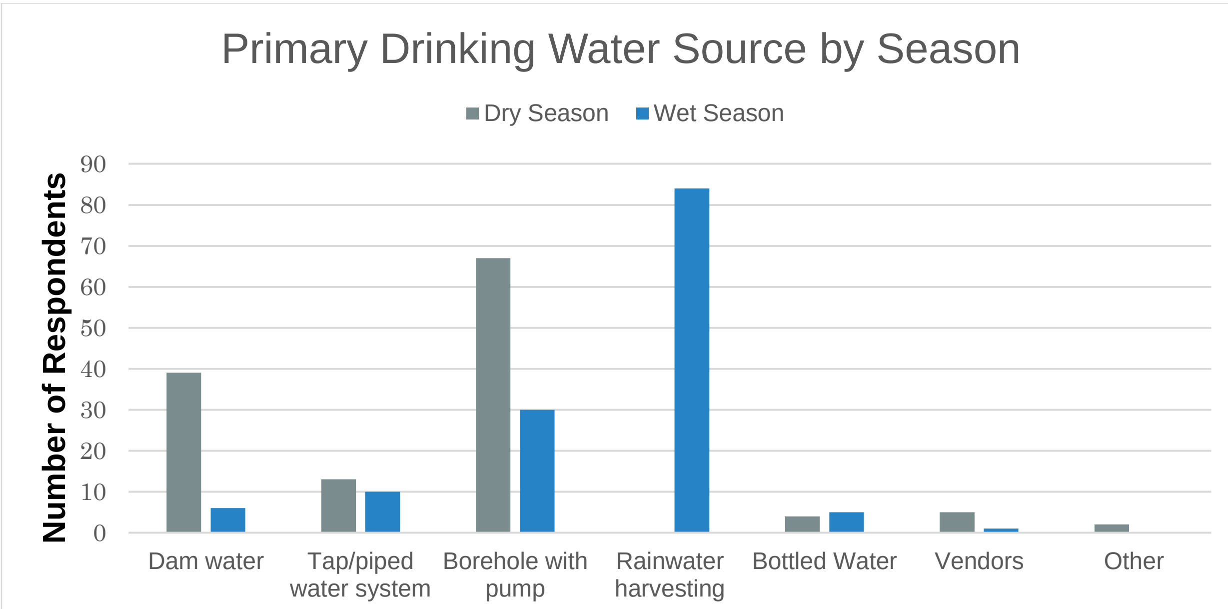

Figure 20. Primary Household Drinking Water Source per Season

The influence of seasonality on household collection habits is reflected in other household survey variables. In Table 9 below, if you look at the breakdown of the average distance traveled by the household in the dry season versus in the wet season you can see an increase of approximately 23% of people who have to travel less than 1 kilometer to their preferred water source, with 24% of respondents traveling that distance in the dry season compared to 47% of respondents in the wet season. If less distance has to be traveled to access the preferred water source, additional time is open for alternate activities, such as work or school.

In both of the water collection examples, the source used and distance traveled, rainwater capture is the key player in the positive outcomes of accessing an improved water source and creating more time for income generating or leisure activities. Exploring additional rainwater capture options and ensuring that rainwater capture is done properly by keeping the flow pathway and storage container clean from debris and properly sealed is advisable.

Table 9. Water Collection Variables

Variables	Measurement	Dry Season N (%)	Wet Season N (%)
Primary Water Source	Dam water	82 (65)	19 (15)
	Tap/piped system	2 (2)	10 (8)
	Borehole	39 (31)	19 (15)
	Rainwater harvesting	0 (0)	85 (66)
	Bottled water	0 (0)	2 (2)
	Vendors	5 (4)	0 (0)
	Other	2 (2)	0 (0)
Primary Drinking Water Source	Dam water	39 (31)	6 (5)
	Tap/piped system	13 (10)	10 (8)
	Borehole	67 (53)	30 (23)
	Rainwater harvesting	0 (0)	84 (66)
	Bottled water	4 (3)	5 (4)
	Vendors	5 (4)	1 (1)
	Other	2 (2)	0 (0)
Distance Traveled to Preferred Water Source (km)	0 - .99	68 (24)	170 (47)
	1 - 1.99	131 (46)	115 (32)
	2 - 2.99	31 (11)	28 (8)
	3 - 3.99	34 (12)	33 (9)
	4 - 4.99	8 (3)	5 (1)
	> 5	15 (5)	14 (4)
Average Cost (UGX/ liter)	Dam	2,530.00	1,051.61
	Surface	N/A	0.00
	Tap	1,858.62	1,384.09
	Borehole	2,398.81	1,056.63
	Rain Water	N/A	131.87
	Bottled	4,863.64	5,863.64
	Vendor	5,000.00	2,987.18
	Other	4,500.00	1,350.00
Average Time to Fill (Hours)	Dam	2.4	1.3
	Surface	N/A	0.5
	Tap	1.6	0.5
	Borehole	4.2	1.5
	Rain Water	N/A	1.8
	Bottled	0.8	1.1
	Vendor	2.9	1.3
	Other	1.3	0.8
Primary Water Collector Gender	Male		76 (60)
	Female		50 (40)
Primary Water Collector Age	< 18		24 (19)
	18 - 33		80 (63)
	34 - 49		17 (13)
	50 - 65		4 (3)
	> 65		3 (2)

As a brief note, one unusual finding came up in analyzing the survey results and that is the make-up of the water collectors. Traditionally women and children are the primary water collectors in a developing country. However, we found the majority of water collectors were males (60% of respondents) or individuals within the 18-33 year old age bracket (62.5% of respondents) while only 40% of women and 18.8% of people under the age of 18 were responsible for collecting water. We hypothesize that this is a result of the young demographic within Migyera. As discussed in the demographics, we anticipate that more households contain single young adults or young families that do not have children old enough to collect rainwater leaving the responsibility of water collection with hired help or the parents. Along these lines, it would be recommended to perform a similar or identical survey as seen in this report in 5 or 10 years to determine if this was indeed the case or if there was an outside factor influencing these water collection habits.

Water Management

Water management is a broad term used for any methods of maintaining, storing, or treating water. Analyzing the storage and treatment of water are two key parts of the second driving question of this study.

Maintaining Water Sources

The population within the Migyera Town Council perceives the strategies for water management to be diverse. 47% of respondents reported that a community committee managed their water supply, followed by 19% reporting a Town Council appointee and 14% reporting a designated well manager.

Water Storage

Water storage is of interest, primarily because of the health implications proper water storage can have. Additionally, water storage is an expected response in any climate with variable precipitation. 78% of households reported that they store their water for more than a day, but only 54% of those who store water keep their storage container sealed. This is important when remembering that 60% of drinking water comes from improved sources in the dry season and up to 90% in the wet season. Unsealed storage containers allow for the possibility of contamination, essentially rendering the benefit of collecting from an improved source useless.

Table 10. Water Management Variables

Variables	Measurement	N (%)
Water Manager	No manager	3 (2)
	Self-managed	12 (9)
	Village leader	7 (6)
	Well manager	18 (14)
	Community committee	60 (47)
	Town Council appointee	24 (19)
	Other	6 (5)
Water Stored (more than 1 day)	Yes	99 (78)
	No	28 (22)
Stored water sealed	Never	23 (23)
	Sometimes	23 (23)
	Always	53 (54)
Frequency wash storage container	Never	6 (6)
	6 months- 1 year	5 (5)
	Monthly	19 (18)
	Weekly	28 (27)
	Every few days	26 (25)
	Daily	2 (2)
	Each use	19 (18)
Material used to wash	Do not wash	6 (5)
	Rinse with water	6 (5)
	Scrub with brush and rinse	2 (2)
	Soap and scrubbing	73 (62)
	Ash, sand, soil, or leaves	28 (24)
	Other	3 (3)
Primary Water Treatment	No treatment	38 (30)
	Boil	81 (64)
	Simple filter	4 (3)
	Other	3 (3)
Seasons water is treated	Do not treat	38 (30)
	Dry season only	12 (10)
	Wet season only	1 (1)
	Both seasons	75 (60)
Frequency of treatment	Do not treat	37 (31)
	Each use	65 (54)
	Daily	6 (5)
	Weekly	10 (8)
	Other	3 (3)
Type of Rainwater Catchment	Roof gutter & drum	53 (42)
	Roof gutter & storage tank	13 (10)
	Small container under roof	14 (11)
	Drum under roof	4 (3)
	Left in open	34 (27)
	Does not apply	11 (9)

Continuing along these lines only 18% of respondents wash their container with each use, while 29% wash it once a month or less. However a majority of respondents (62%) report that they scrub with soap when washing out their container. The remainder of the respondents that wash out their containers are using alternative sources, such as ash, soil, or rocks. By using these alternative methods, it is possible that the containers are actually becoming contaminated during the washing process as these substances can house microbes that will transfer into the container.

Water Treatment

Water treatment is another key step in proper water management. While we were concerned with how people are treating their water, we see that treatment methods vary depending on the water source that was used. Table 9 below shows two cross-tabulations were performed comparing the reported primary drinking sources in both the wet and dry season to the treatment methods. Please note that these only include the primary source for drinking water and the primary treatment methods per household. A few households did combine treatment methods (i.e. simple filter and boil). Although it is initially concerning that approximately 30% of households surveyed do not treat their drinking water during the dry season, of those only 22% of households are getting their water from the dam, the only reported surface water source. The water collected from the dam accounts for the majority of the 28% of households that are getting their water from an unimproved source during the dry season.

Of the people who are reporting that they are not treating their water, 76% are getting their water from an improved source in the dry season, which goes up to 90% in the wet season. This means that only 9.7% of households are not treating water from an unimproved source in the wet season. Overall there is an 18% decrease in households getting water from unimproved sources and not treating them. This is completely due to the seasonality and the ability to capture rainwater during the wet season.

It should be noted that while enumerators asked for the primary drinking water source, on occasion, respondents provided multiple sources. Additionally, Table 9 shows us that the overwhelming majority of respondents treat primarily through boiling their water or not treating it at all. Approximately 5.4%, when combining the dry season and the wet season, are primarily treating their drinking water through alternative sources. This is important to remember when planning any sort of intervention that would alter the current habits in the community, such as the introduction of an advanced filter to remove sediment from surface water or chlorine.

Table 11. Seasonal Water Source vs. Treatment Method

What is your primary source of drinking water during the dry season?

	Dam water	Tap/piped water system	Borehole with pump	Rainwater harvesting	Bottled Water	Vendors	Other	Total
Do not treat	8	1	27	0	2	1	0	39
Boil	30	10	36	1	1	3	2	81
Simple filter	1	2	1	0	0	0	0	4
Advanced filter	0	0	0	0	0	0	0	0
Use chemicals	0	0	1	0	0	0	0	1
Defluoridization	0	0	0	0	0	0	0	0
Other	0	0	1	0	1	0	0	2
Total	39	13	66	1	4	4	2	125

What is your primary source of drinking water during the wet season?

	Dam water	Tap/piped water system	Borehole with pump	Rainwater harvesting	Bottled Water	Vendors	Other	Total
Do not treat	2	2	15	20	2	0	0	41
Boil	4	8	14	58	2	0	0	86
Simple filter	0	0	0	4	0	0	0	4
Advanced filter	0	0	0	0	0	0	0	0
Use chemicals	0	0	0	1	0	0	0	1
Defluoridization	0	0	0	0	0	0	0	0
Other	0	0	0	1	1	0	0	2
Total	6	10	29	84	5	0	0	134

We also looked at household perceptions of the effectiveness of different treatment methods on drinking water safety. One concerning finding was that 20 respondents or approximately 16.5% reported that they thought their water was definitely not safe to drink or probably not safe to drink even after any sort of treatment. From this group, 20% are boiling their water as their treatment method. This is especially perplexing that these households would undergo a treatment method that they did not feel was effective. The other 20% within this category are not treating their water. This could point to a portion of the population that is not currently able to pay for materials involved in the treatment process, including timber used for boiling water.

Another finding that caused worry is the number of households who are unsure if the water is safe to drink, either at the source or after treatment. 44.5% of households are not sure if their water is safe at the source, which only drops down to 36.4% after treatment with the majority

(54.5%) reporting that they do not treat their water. We recognize that this could be a self-reporting bias from the survey administration. The presence of outsiders, even if not the ones directly administering the survey, may have skewed some of these answers as respondents were afraid to give a 'wrong answer' in fear of judgement. Those who felt this way may have been a part of the contingent that decided to answer 'Do Not Know' as well.

Table 12. Perception of Drinking Water Safety Before and After Treatment

How safe do you think your primary drinking water is when you collect it at the source?						
	Definitely not safe to drink	**Probably not safe to drink**	**I am not sure if it is safe**	**It is probably safe to drink**	**It is definitely safe to drink**	**Do not know**
Do not treat	10	2	21	2	3	0
Boil	28	8	30	3	11	1
Simple filter	1	0	3	0	0	0
Advanced filter	0	0	0	0	0	0
Use chemicals	0	0	1	0	0	0
Defluoridization	0	0	0	0	0	0
Other	1	0	1	0	0	0
Total	40	10	56	5	14	1

How safe do you think your primary drinking water is at the time you drink it (after treatment, if applicable)?						
	Definitely not safe to drink	**Probably not safe to drink**	**I am not sure if it is safe**	**It is probably safe to drink**	**It is definitely safe to drink**	**Do not know**
Do not treat	3	1	24	3	7	0
Boil	8	8	16	14	30	5
Simple filter	0	0	2	1	1	0
Advanced filter	0	0	0	0	0	0
Use chemicals	0	0	1	0	0	0
Defluoridization	0	0	0	0	0	0
Other	0	0	1	1	0	0
Total	11	9	44	19	38	5

The final category, those who think the water is probably safe to drink and definitely safe to drink rose from 15% at the source to 47% after treatment. While this certainly should be the case after any sort of treatment, these perceptions do not align with the microbial testing explained in the above section. With 13.1% of household water samples coming back with zero contamination, which is clearly below the perception that 47% of households within the Migyera Town Council had about their water quality. This discrepancy may be due to a variety of factors including when water is treated (i.e. before or after storage) and how water is being treated. In an effort to save firewood, household may be boiling water for less than the recommended time period or may not be allowing the water to reach a rolling boil. More research will have to be done to determine the exact cause of this inconsistency.

The next step in this analysis was comparing these perceptions to the primary drinking water sources. As we found out in evaluating water treatment, no treatment did not mean households were collecting water from an unimproved source.

In Table 13 below, during the dry season 50% of respondents who perceive their water to be definitely safe to drink at the time they collect it from the source are getting their water from an unimproved source. Of those collecting from an unimproved source, 75% are getting their water from a dam. This number is substantially higher than anticipated as the experiences from the Duke University team seemed to show that most people understood that the dams were very contaminated. It could be possible that these respondents are speaking of personal dams within their property, a common feature in some of the rural villages like Nalukonge.

When we compare those figures to the wet season, only 33% of respondents who perceive their water to be definitely safe to drink at the time they collect it from the source are getting their water from an unimproved source. As we've seen throughout our analysis, this decrease is from the classification of rainwater as an improved water source.

On the opposite end of the spectrum, there were a surprising amount of people who felt their drinking water was definitely not safe to drink, even when collecting from an improved source, like a borehole. In the dry season, 53.8% of respondents who said they thought their primary drinking water source was definitely not safe upon collection were collecting from improved sources. This perception continued even after treatment, with 63.6% of respondents claiming their water was definitely not safe with all respondents collecting from a borehole. Comparing this to the wet season, we found that 95.1% of respondents who felt their primary drinking water was definitely not safe to drink upon collection got their water from an improved water sources. These sources included the piped system, boreholes, and rainwater collection. After treatment, 100% of respondents who felt their drinking water was definitely not safe to drink had collected their water from an improved source.

Table 13. Perception of Drinking Water Safety Compared to Water Source

Dry Season

	How safe do you think your primary drinking water is when you collect it at the source?						*How safe do you think your primary drinking water is at the time you drink it (after treatment, if applicable)?*					
	Definitely not safe to drink	**Probably not safe to drink**	**I am not sure if it is safe to drink**	**Probably safe to drink**	**Definitely safe to drink**	**Do not know**	**Definitely not safe to drink**	**Probably not safe to drink**	**I am not sure if it is safe to drink**	**Probably safe to drink**	**Definitely safe to drink**	**Do not know**
Dam water	14	3	16	0	6	0	4	3	11	5	16	0
Tap water system	2	0	6	1	4	0	0	0	6	1	5	1
Borehole	19	6	33	3	4	1	7	6	26	8	16	3
Bottled Water	2	0	1	1	0	0	0	0	1	2	1	0
Vendors	2	0	1	0	2	0	0	0	0	3	1	1
Other	0	1	0	1	0	0	0	0	0	2	0	0
Total	39	10	57	6	16	1	11	9	44	21	39	5

Wet Season

	How safe do you think your primary drinking water is when you collect it at the source?						*How safe do you think your primary drinking water is at the time you drink it (after treatment, if applicable)?*					
	Definitely not safe to drink	**Probably not safe to drink**	**I am not sure if it is safe to drink**	**Probably safe to drink**	**Definitely safe to drink**	**Do not know**	**Definitely not safe to drink**	**Probably not safe to drink**	**I am not sure if it is safe to drink**	**Probably safe to drink**	**Definitely safe to drink**	**Do not know**
Dam water	0	0	2	0	4	0	0	0	2	0	4	0
Tap water system	4	0	3	1	2	0	2	0	2	1	3	2
Borehole	11	3	12	1	2	0	3	2	12	5	6	1
Rainwater Harvesting	24	7	43	2	7	1	6	7	31	11	26	3
Bottled Water	2	0	1	1	1	0	0	0	1	2	2	0
Vendors	0	0	0	0	1	0	0	0	0	1	0	0
Total	41	10	56	5	15	1	11	9	44	20	38	5

Based on our bacteriological testing, we know that the majority of sources classified as improved are indeed free from contamination. As discussed earlier, those sources that did contain contamination were likely outliers, with the contamination caused by the coverings on the pumps and not from the groundwater itself. However, if these sources are viewed as unsafe when collected, it is likely that illness was caused as a result of drinking from these sources. We are brought back full circle to looking at water storage. If people are getting sick from these sources that are clean when they come out of the tap, pump, or sky, contamination is introduced through another avenue. This could include storage containers or catchment systems that are dirty before the water enters, or open containers that have contamination enter as they are left exposed.

Sanitation

Sanitation variables were important to capture based on the health implications poor sanitation, such as lack of hand washing, may have on a community. Table 14 below shows the sanitation variables from the household survey.

Although we feel many of our variables are representative of the community attitude as a whole, there are several key instances where observations and self-reporting conflict. In sanitation, we are particularly referring to those community members that do not have a latrine. 94% of respondents reported that they used either a pit or VIP (Ventilated Improved Pit) latrine. Of the 6% that reported they did not have a latrine, only 1 respondent reported going 'in the bush' with the other respondents reporting they used a neighbor's latrine. We feel that this is attributed to a self-reporting bias. As mentioned earlier, respondents may feel uncomfortable telling someone who is working with an outsider to the community personal things that may be embarrassing, including not having a household latrine. When GPS units were available, the presence of a latrine was independently verified by a Duke team member and data was collected on different characteristics as detailed in our Methods section.

One of the findings of most significance in the sanitation variables was the occurrences of people who reported they always wash their hands in certain instances. Like above, we imagine that these numbers are inflated based on the perceptions around hand washing to what they are in reality. 33% of respondents say they are always washing their hands after using the latrine with another 31% always washing their hands after cleaning a child's bottom. The highest figure, before eating food, was at 40% of people always washing their hands and the lowest, after handling animals, was 20%. This means that between 60-80% of the respondents are not consistently washing their hands in scenarios where hand washing is strongly encouraged in order to prevent the spread of disease. Several factors, including ease of access to soap and water and the cost of those materials may be preventing constant hand washing. This may also be from not understanding the relationship between hand washing and illness.

Table 14. Sanitation Variables

Variables	**Measurement**	**N (%)**
Latrine Type	Pit latrine (ordinary)	95 (75)
	VIP latrine (ventilated)	24 (19)
	No latrine	7 (6)
If no latrine, what is used	In the bush	1 (14)
	Neighbor's latrine	6 (86)
Depth of latrine pit (feet)	< 10	2 (1.6)
	15	4 (3.3)
	20	5 (4.1)
	25	3 (2.4)
	30	9 (7.3)
	40	12 (9.8)
	45	1 (0.8)
	50	13 (10.6)
	55	1 (0.8)
	60	2 (1.6)
	Do not know	71 (57.7)
Satisfaction with current latrine	Not at all satisfied	29 (23)
	Somewhat dissatisfied	11 (9)
	Neutral	6 (5)
	Satisfied	59 (47)
	Very satisfied	20 (16)
Hand-washing Station Present	Yes	71 (57)
	No	53 (43)
Hand-washing Reported Always at Critical Points	After using toilet	42 (33)
	Before preparing food	35 (29)
	Before eating food	51 (40)
	After cleaning child's bottom	27 (31)
	After handling animals	11 (20)
Materials used to wash hands	Water	121 (98)
	Soap	113 (91)
	Other	2 (2)
Household member with diarrhea in past 24 hours	No	98 (77)
	Yes	29 (23)

Recommendations

Based on the analysis we have developed two sets of recommendations that we would encourage ChangeALife Uganda to implement and incorporate into their long-term water and sanitation strategy. One set of recommendations is general recommendations that are representative of international best standards and practices while the second set is specific to problems within the Migyera Town Council.

> 3. *What measures can be implemented to ensure the community's access to a sufficient supply of potable water?*

Overall Recommendations

International guidelines provide a basis for drinking-water quality[20] and should be adhered to improve health standards. Three categories in our general recommendations section address the incorporation of these guidelines into community practice.

Water Storage

One of the common problems observed both in the field and in the results has been microbial contamination occurring between collection and consumption, as shown through the bacteriological water testing first at the source and then at the household level. In order to preserve the integrity of clean water, water storage methods including cleaning and covering containers should be addressed. Simple measures are sufficient, such as covering the storage container when not in use and ensuring that both the container and any delivery method used to transport the water is sufficiently contaminant free. In the context of Migyera, this would involve halting the use of alternative methods in storage container cleaning, such as soil, and protecting the supply of water from any animals or debris it may come in contact with covering the container. Note that water storage is separate from water treatment and treated and untreated water should not be mixed in the storage container. While simple in practice, these small

[20] Our general recommendations are heavily influenced by the Fourth Edition of the WHO Guidelines for Drinking-water Quality. These guidelines are used to develop national standards world-wide and represent the UN's official position on drinking water quality.

changes may require behavioral adjustments on the part of the community members within the Migyera Town Council.

Water Treatment for Microbial Contaminants

Treatment for microbial contaminants is most easily done through boiling water as it can kill human pathogens, even in turbid water and high altitudes, only requiring materials to heat it to a rolling boil. At a rolling boil, approximately 100°C most bacteria will be rendered inactive after five minutes of boiling. Boiling times are slightly longer for viruses and protozoa, a full list of bacteria, viruses, and protozoa along with boiling temperature and times can be found in the appendix (WHO 2011). It is important to stress proper boiling times, as treatment will not be effective if they are not met. Groundwater supplies can be kept safe by properly encasing bores to a reasonable depth and sealing the bore heads to prevent contamination from surface water. Looking at groundwater in the context of Migyera, it is especially important that these measures are undertaken at every site because the fractured aquifer structure may allow for rapid transport of contaminants into the supply. Any water collected at the dams or any other surface water sources should be filtered, preferably though a multi-stage filter, before any treatment. Additionally as further protective measures chemical treatment such as chlorine or iodine could be applied to water being stored for longer periods of time within the household though this would not be recommended as an alternative to boiling water before each use due to the potential for recontamination of the source.

Education

Any changes, no matter how small they may seem, require education to ensure best practices are widely and accurately distributed throughout the community. It is recommended that ChangeALife Uganda assist in educational campaigns on the following: water treatment, particularly good boiling practices; proper water storage methods; and sanitation programming including the importance of hand washing which can prevent water related diseases.

Information Sharing

One of the most important things we recommend that ChangeALife institute immediately is transparent and open communication with the Migyera Town Council. With our direct communications with the town counsel they expressed interest in cooperation with the CALU as well as a few of their own initiatives that CALU may be interested in. Information sharing and cooperation between the two could benefit both parties and the community as a whole.

Migyera Specific Recommendations

Within the Migyera community we recognize there are challenges specific to the area due to the unique climatic and geologic characteristics of the region. The following recommendations address these challenges.

Water Treatment for Chemical Contaminants

The two primary chemicals that we encourage CALU to monitor include arsenic and fluoride. Both are naturally occurring based on the bedrocks that the water has filtered through before entering the aquifer. Arsenic is commonly treated by coagulation and small-scale treatment technologies are available. As the wells contaminated by arsenic fall outside of the CALU scope, we will not detail these strategies. However, at the household level those who are collecting water from wells with high arsenic levels would be advised to dilute the high arsenic water with bacteriologically safe low-arsenic water or not use the high-arsenic water for consumption or cooking. Fluoride is of particular importance to CALU as the newly drilled borehole is close to fluoride exceedance levels. The well should be monitored closely to check that the fluoride content does not surpass recommended standards. Fluoride can be treated at either the source or household level. Methods can include membrane filtration technologies like reverse osmosis and nanofiltration or precipitation-coagulation methods. However these methods, especially those for the household, do not need to be taken under great consideration unless further testing shows that fluoride levels are rising toward the exceedance standards.

Rainwater Collection

Seasonality causes a substantial amount of variation between the use of improved and unimproved sources. By expanding rainwater capture systems more people will have access to improved water sources during the wet season. However, it is important that this capture is done in a way to ensure that contamination is not occurring. This includes regularly cleaning the rain gutter under the edge of the roof, trimming branches that may hang over the roof (so as to prevent roof access to small mammals and additional debris from the foliage), and the use of leaf litter strainers. Also, the use of a first-flush system is advised. These systems prevent the first 20-25 liters of water from entering the collection tank, allowing the water to instead wash away any potential contaminants.

While conducing household surveys throughout Migyera Town Council we were able to observe many of the rainwater catchment systems that were in place. Many were crude, a simple gutter into an uncovered storage container. Providing the community with workshops on installing and properly maintaining a rainwater collection system especially focused on properly sealing tanks has the possibility to cut down of the contamination we observed at the household levels.

Groundwater Management

It is essential that a ground water management and policy plan is implemented for the CALU borehole and possible on a larger scale. With two boreholes potentially drawing from the same fractured aquifer borehole yields should be regularly checked to determine if drawdown of the aquifer is occurring more quickly than expected. Part of this plan would be to invest in determining the recharge rate of the surrounding area. Understanding the recharge rate of the borehole and aquifer can help establish a schedule of acceptable times when to pump and times when not to pump to avoid overdrawing the aquifer.

A plan for routine chemical analysis of the CALU borehole should be established specifically checking for arsenic and fluoride. Even though the CALU borehole met the Uganda and WHO standards for both or study was restricted to a short time scale and concentrations may vary with the seasonality of the region and movement of water through a fractured aquifer system.

Because of the uncertainties of the groundwater movement in the area and concerns with ground water contamination from latrines it is strongly advised whenever possible to check for bacterial contamination. Though we do not believe this is an issue in the Migyera Town Council area it has been observed in similar area that bacterial contamination from latrines can occur.

Further Areas of Research

Although our research was able to provide a baseline for future work, both for monitoring and evaluation purposes to evaluate progress and for other research to be based off of, there are many areas that we were unable to assess fully. Many of these were questions that arose both while administering the surveys and when analyzing our data.

Water Treatment

To provide the best recommendations for water treatment it would be wise to continue the evaluation of how water is currently being treated through self-assessments and observations. We recommend that studies evaluating if the water reaches a full boil, the length of the boil, if boiled water is cooled naturally, and if treated water is stored after treatment or used immediately would provide insight as to behaviors within the community. This information could be combined to create targeted educational campaigns. Right now we can only work on conjecture from the data collected.

Groundwater Management

In order to develop a comprehensive management plan for the community, consisting of recharge rates of individual boreholes to mitigate water stress in the dry season, it would be advisable to collect additional information on the groundwater. We recommend that CALU hire consultants to assess the individual recharge rates by using tracers.

Water Reclamation

Reclaiming grey water for household use could prove to relieve water stress, particularly in the dry season when Migyera is faced with increasing water scarcity. However, there are associated risks from using greywater, mainly from excreta-related pathogens. Looking at how the greywater would be used, if the community would be open to using greywater either for agricultural purposes or drinking water, and testing individual household filtration systems would be a good place to begin considering the implementation of greywater education and promotion.

Behavioral Change

For many of our recommendations to be implemented successfully, it is important to know how receptive the community will be to behavior change. We recommend that such an analysis take place before instituting any strategy that requires intensive adoption, such as chlorine treatment or sanitation educational campaigns. A behavior change assessment can be performed by piloting small programs, like the regular cleaning of gutters to prevent contamination and understanding how and why they were adopted by the community. Behavioral change is never going to be a short-term solution; however, these pilots should provide an idea on how open the community is to alternate approaches.

Appendices

A. Duke Consultant Team Biographies

Elizabeth Kendall began her training in the field of Water, Sanitation, and Hygiene (WASH) as an undergraduate intern during her semester abroad in Mexico. It was during this time she learned how to construct dry composting latrines, conduct interviews, and lead community workshops. Interested in public health, Liz has worked taking water samples from wells and preparing public health brochures about the dangers of groundwater contamination by coal ash in rural North Carolina. She is currently a 2015 candidate for a Masters in Environmental Management at Duke University.

Francis Oggeri is currently a second year dual degree student, working to obtain a Masters of Environmental Management program at Duke focusing on water resource management and a Masters of Forestry. His undergraduate degree in Environmental Sciences from the University of Vermont gave him experience working with community members and administering surveys to the public at Acadia National Park. His particular interest is in water resource management, hydrology, and water scarcity and availability.

Alayne Potter graduated with a Bachelors in Political Science from Rice University in 2011 and is a 2015 candidate for a Masters in Environmental Management from Duke University. Currently specializing in international water resources, Alayne is a seasoned professional in the international development sector, working on inter-disciplinary teams with topics ranging from studying the adoption of clean cookstoves in India to evaluating land surface characteristics to assessing water chemistry. She plans to continue managing international water projects in the future.

B. Focus Group Questions

May 21, 2014

1. What do you do with the water you have used for household purposes? (cleaning, washing clothes, etc)
2. Do you collect water you use for household chores at the same source as water you drink?
3. Do you reuse any of your water? If so, which water and how?
4. How often do you consume bottled water?
5. When was the last time you purchased bottled water? Why did you choose to buy bottled water?
6. How much bottled water do you typically but at one time?
7. How much would you be willing to pay for a bottle of water?
8. How much would you be willing to pay to fill a 20L jerrycan with clean water?
9. How much does it cost for you to fill a 20L jerrycan with water (including transport)?
10. How many sources do you collect water from?
11. Do you use different water sources during different times of the year?
12. Why do you use the water source(s) that you do?
13. What made you pick the water source(s) that you use?
14. How comfortable would you be talking about your annual income?
15. What is your annual income?
16. Would you be willing to provide your name and phone number?

17. Where do you use the toilet? What type of toilet is it?
18. What is your preferred toilet for your household (if cost were not an issue)?
19. Do you wash your hands? Why or why not do you choose to wash your hands?

May 22, 2014:

1. Where do you pee and/or poop?
2. Where do your children (under the age of 5) pee and/or poop OR where is their waste disposed?
3. Did you build your own latrine or did you hire someone to build it?
4. Where do you dispose of water you have used for household cleaning?
5. Do you collect rainwater
    a. If yes:
        i. What is the capacity/How many jerrycans does it fill?
        ii. How many days does it last in your household?
        iii. How many people are in your household?
        iv. What do you use collected water for?
    b. If no:
        i. Why do you not collect rainwater?
        ii. What is your reason for not using rainwater?
6. Do you wash your hands? What is your reason for washing (or not washing) your hands?
7. Would you want more boreholes built in the community? Why or why not?
8. Do you know, on average, how much money you make in a year? Would you tell us?
9. Would you be willing to give us your name and phone number?

Focus Groups: Duke Water Project – Migyera, Uganda

Scheduled for May 29th, 2014

Introduction

We are a team of three Duke University students from the United States. We are independently conducting this research on behalf of ChangeALife Uganda.

The purpose of this focus group is to discuss your habits and knowledge related to water and sanitation and health within the Migyera Parrish. Today we will lead a discussion that will include questions about how water is collected and stored and your sanitation habits like hand-washing and latrine use. Taking part in this study is completely voluntary. There is the risk that you may find some of the questions to be sensitive. This is not intentional, and you may decide to not answer any question that you do not feel comfortable answering. If you decide to not answer some questions, it will not affect your current or future relationship with Duke University or ChangeALife Uganda. The discussion will take place for approximately one hour. With your permission, we would also like to tape-record the interview.

Your answers will be confidential. The records of this study will be kept private. In any sort of report we make public, we will not include any information that will make it possible to identify you. If we tape-record the interview, we will destroy the tape after it has been transcribed, which we anticipate will be within six months of its taping.

This discussion will help us develop the survey that will be taking place in the Migyera Parrish in the upcoming weeks. The survey will ultimately influence recommendations we provide to ChangeALife Uganda for future projects that will occur in the Migyera Parrish.

Please ask us any questions you may have before we begin our discussion.

Participants ask any questions they have. Go around the room and have participants say their name and the village they are from.

Scenarios (for men's only and women's only – NOT mixed group)

Women: Please explain all the steps involved with preparing a meal for dinner – be as detailed as possible.

Men: Please explain what you do at the end of the day between leaving work and eating dinner with your family – be as detailed as possible.

Hand washing/ hand hygiene

- How do you wash your hands?
- What do you use when you wash your hands?
- Do you ever use a material other than soap and water when washing your hands?
- How much do you typically pay for soap?
- How often do you purchase soap?
- Have you ever seen promotional materials in the Migyera Parrish about hand washing?
- Do you see a difference in your health when you wash your hands than if you do not wash your hands?
- Do you see a difference in your health if you wash your hands with soap and water than if you only wash your hands with water?
- How many times a day do you wash your hands?
- When do you think it is most important to wash your hands?
- When do you think the second most important time to wash your hands is?
- What makes these times important to you?
- If you have a hand washing station, where is it located on your property?
    - Why did you choose that location?
    - What is the main source of water?

Sanitation

- Are there people in the village/parrish that do not have latrines?
    - If yes, where do those people piss/poop?
- What type of latrine do you have in your household?
    - Do you have more than one? If so, how many?
    - If you do not have a latrine what do you use?

- Do people outside of your family use your latrine?
    - Do you charge them? If so, how much?
- What other types of latrines or toilets have you seen or heard about?
- How many people use your household latrine?
- Who built your current latrine?
- When was your latrine installed?
- What materials were used to construct your latrine?
- How much did it cost to build the latrine?
- How did you determine where to install your latrine?
- How was the size of the latrine's hole determined?
    - How deep is the hole?
- What do you do when your latrine becomes full?
- Have you ever had you latrine emptied or emptied the latrine yourself?
    - How was it emptied?
    - How long ago was it emptied?
- What is the most common complaint you have about the latrine in your household?
- Do you clean yourself after pooping?
    - What do you use?
    - Where do you dispose of the material used?
- What made you get a latrine? Rank from most to least important
    - Because that is what people do
    - Because I think it is important for my health
    - Because I don't like the smell
    - Because I want privacy
    - Because it keeps my property clean
    - Other: Please explain
- Overall, how satisfied are you with your pit/vip latrine?
- Do you have any plans to change your latrine or upgrade your latrine in the next two years?
- How far away is the nearest public toilet from your house?
    - When was it built?
- Do you use the public latrine?
    - Does it cost money to use? If yes, how much money?
- Is there a flushing toilet within the village?
    - If yes, where is it located?

Animals

- Do you own animals?
- Where do the animals stay during the day?
    - Where do they stay at night?
- Where do your animals poop?
- Do you use your animals' waste (poop) for any purpose?
- Are your children involved in caring for your animals?
- Where do you get the water for your animals during the wet season?
    - During the dry season?

  - Do you treat it at any time in the year?
  - Do you store collected water for your animals?

Rain water collection

- Do you collect rainwater for any purpose in your household (including to water animals)?
  - What system of rainwater capture do you use? Please elaborate.
  - How large are the containers that are used to capture rain water (in liters)?
- How long does a full container of stored rainwater last your household?
- How many members from your household use your stored rainwater as a source of water?
- How many people outside your household use your stored rainwater as a source of water?
  - Do you sell it? How much does it cost?
- If you do not currently collect rain water, would you be interested in setting up a rain water collection system for your household?
  - What are the reasons why you do not currently collect rainwater?
- Is rainwater collection a primary (significant) source of water for your household?
- Do you treat your rainwater before you use it in your household?

C. Survey Consent Form

Survey Consent

Hello, my name is ________________. I am here today with a team of students from Duke University in the United States. We are conducting this research on behalf of ChangeALife Uganda.

You are being asked to take part in a survey on your habits and knowledge related to water and sanitation and health. We are asking you to take part because you live within the Migyera Town Council. Please listen to the following statement carefully and ask any questions you may have before agreeing to take part in the study.

What the study is about: The purpose of this survey is to learn about the different water collection and sanitation habits within the Migyera community.

What we will ask you to do: If you agree to take this survey, we will conduct a brief interview immediately following this statement. The interview will include questions about water within Migyera Town Council, including how it is collected, treated and stored, recent health concerns that they may have experienced, and sanitation habits like hand-washing. The interview will take about 30-45 minutes to complete.

Risks and benefits: There is the risk that you may find some of the questions conditions to be sensitive.

The benefit is that these survey results will influence recommendations for future projects within the Migyera community.

Compensation: There is no compensation upon completion of the survey.

Your answers will be confidential. The records of this study will be kept private. In any sort of report we make public we will not include any information that will make it possible to identify you. Research records will be kept in a locked file; only the researchers will have access to the records.

Taking part is voluntary: Taking part in this study is completely voluntary. You may skip any questions that you do not want to answer. If you decide not to take part or to skip some of the questions, it will not affect your current or future relationship with Duke University or Change-A-Life Uganda. If you decide to take part, you are free to withdraw at any time.

If you have questions: The researchers conducting this study are Francis Oggeri, Elizabeth Kendall and Alayne Potter. Please ask any questions you have now. If you have questions later, you may contact Francis Oggeri at francis.oggeri@duke.edu, Elizabeth Kendall at elizabeth.kendall@duke.edu, and Alayne Potter at alayne.potter@duke.edu.

If you have any questions or concerns regarding your rights as a subject in this study, you may contact the Institutional Review Board (IRB) at 1-919-684-3030 or access their website (http://www.ors.duke.edu/research-with-human-subjects).

Please verbally indicate that you have listened to the statement, received answers to any questions you have asked and agree to participate. If yes, please say, “I consent to take part in the study.”

In addition to agreeing to participate, do you also consent to having a water sample taken at your household from your primary drinking water storage container? If yes, please say “I consent to have a water sample taken at my household.”

Thank you, please let me begin the survey.

D. Household Survey

1	**Survey Administration**			
1.1	Date *(Western Date)*	*(Day)*__________	[June] [July]	2014
1.2	Household ID			
1.3	Interviewer Initials			
1.4	Verbal Consent Given?	[0] No [1] Yes		
1.5	Name of Head of Household			
1.6	Village Name			
1.7	Mobile phone contact number			
1.7.1	Mobile phone contact name			
1.8	Time Started *(24 hour time)*	H M		
1.8.2	Time Finished *(24 hour time)*	H M		
1.9	Survey Quality Check by:	Date:		

2	**Demographic Information**		
2.1	Name of respondent		
2.1.1	Gender of respondent	[1] Male [2] Female	
2.1.2	Age of respondent	[Years] ________________________________	
2.2	Tribe	[1] Baganda [3] Banyankole [2] Baluri [4] Banyoro [-95] Other:_____________________________	
2.3	What languages are spoken in your household? (*Mark all that apply*)	[1] Luganda [3] Lunyankore [2] Luluri [4] Luo [-95] Other:_____________________________	
2.4	Religion	[1] Muslim [2] Christian – Orthodox [3] Christian – Protestant [4] Christian – Catholic	[5] Traditional:___________ [6] No religion [-95] Other:______________ [-99] Refuse

2.5	How many years have you lived here in this village?	[Years] ________________________
2.6	How many total people, including children, currently live in your household and share in meals?	[People] ________________________
2.7	Does the number of people in your household change depending on the season? If so, when is the number greatest?	[0] Does not change [-95]Other:___________________ [1] Changes, greatest in rainy season [2] Changes, greatest in dry season [-99] Does not apply
2.7.1	*If changes:* When these people are not in your household, where do they go?	[0] Do not go [1] School [2] Work [3] To seek work [4] With animals [-95] Other:____________________

3	**Water Sources**				
	I am going to ask you about all the sources you use for water this year.				
		3.1 During the past year, did you use water from [SOURCE] during the dry season only, the wet season only, or both?	3.1.1 During the last dry season for what purposes did you use [SOURCE]? ***Do not** read options*	3.1.2 During the last wet season for what purposes did you use [SOURCE]? ***Do not** read options*	3.2 What form of transportation do you normally use to transport water from [SOURCE] to your house? ***Do not** read options*
		[0] No [1] Dry Season [2] Wet Season	[1] Drinking [2] Cooking [3] Bathing [4] Washing [5] Animals [6] Industry [7] Farm/irrigation [-95] Other: ________________ [-99] Does not apply	[1] Drinking [2] Cooking [3] Bathing [4] Washing [5] Animals [6] Industry [7] Farm/irrigation [-95] Other: _________________ [-99] Does not apply	[0] No transport needed [1] Walking/carrying [2] Using animals [3] Hired transport [4] Personal transport [-95] Other:_______________ [-99] Does not apply
	1. Dam water	[0] [1] [2]	[1] [2] [3] [4] [5] [6] [7] [-95] [-99]	[1] [2] [3] [4] [5] [6] [7] [-95] [-99]	[0] [1] [2] [3] [4] [-95] [-99]
	2. Surface water (rivers, lakes)	[0] [1] [2]	[1] [2] [3] [4] [5] [6] [7] [-95] [-99]	[1] [2] [3] [4] [5] [6] [7] [-95] [-99]	[0] [1] [2] [3] [4] [-95] [-99]
	3. Tap/piped water system	[0] [1] [2]	[1] [2] [3] [4] [5] [6] [7] [-95] [-99]	[1] [2] [3] [4] [5] [6] [7] [-95] [-99]	[0] [1] [2] [3] [4] [-95] [-99]

	4. Borehole with pump	[0] [1] [2]	[1] [2] [3] [4] [5] [6] [7] [-95] [-99]	[1] [2] [3] [4] [5] [6] [7] [-95] [-99]	[0] [1] [2] [3] [4] [-95] [-99]
	5. Dug well	[0] [1] [2]	[1] [2] [3] [4] [5] [6] [7] [-95] [-99]	[1] [2] [3] [4] [5] [6] [7] [-95] [-99]	[0] [1] [2] [3] [4] [-95] [-99]
	6. Rainwater harvesting	[0] [1] [2]	[1] [2] [3] [4] [5] [6] [7] [-95] [-99]	[1] [2] [3] [4] [5] [6] [7] [-95] [-99]	[0] [1] [2] [3] [4] [-95] [-99]
	7. Bottled Water	[0] [1] [2]	[1] [2] [3] [4] [5] [6] [7] [-95] [-99]	[1] [2] [3] [4] [5] [6] [7] [-95] [-99]	[0] [1] [2] [3] [4] [-95] [-99]
	8. Vendors	[0] [1] [2]	[1] [2] [3] [4] [5] [6] [7] [-95] [-99]	[1] [2] [3] [4] [5] [6] [7] [-95] [-99]	[0] [1] [2] [3] [4] [-95] [-99]
	9. Other: ___________	[0] [1] [2]	[1] [2] [3] [4] [5] [6] [7] [-95] [-99]	[1] [2] [3] [4] [5] [6] [7] [-95] [-99]	[0] [1] [2] [3] [4] [-95] [-99]

3	**Water Sources Continued**	
3.3	What is your primary source of water during the dry season?	[1] [2] [3] [4] [5] [6] [7] [8] [9]
3.3.1	What is your primary source of drinking water during the dry season?	[1] [2] [3] [4] [5] [6] [7] [8] [9]
3.4	What is your primary source of water during the wet season?	[1] [2] [3] [4] [5] [6] [7] [8] [9]
3.4.1	What is your primary source of drinking water during the wet season?	[1] [2] [3] [4] [5] [6] [7] [8] [9]
3.5	In the past six months, were you unable to get water from a water source that you use? If so, when?	Time: ______________ Circle Unit: [1] Days [2] Weeks [3] Months [4] Have not experienced shortage [-99] Do not know
3.5.1	How long did that shortage last?	Time: ______________ Circle Unit: [1] Days [2] Weeks [3] Months [4] Have not experienced shortage [-99] Do not know

4	**Collection**						
	4.1 How far does it take you to travel to your preferred [SOURCE]?	4.2 During the **dry** season, what is the average time, including waiting, to fill your containers at this [SOURCE]?	4.2.1 On average, in the **dry** season how many jerrycans (yellow 20 liter) of water do you use from [SOURCE] each day at home during the dry season?	4.2.2 How much is paid during the **dry** season, including all fees, expenses and costs you have on average for [SOURCE] each day for household water use?	4.3 During the **wet** season, what is the average time, including waiting, to fill your containers at this [SOURCE]?	4.3.1 On average, in the **wet** season, how many jerrycans (yellow 20 liter) of water do you use from [SOURCE] each day at home?	4.3.2 How much is paid during the **wet** season, including all fees, expenses and costs you have on average for [SOURCE] each day for household water use?
Units: [-99] Does not apply	Write Amount, Specify Units	Write Amount, Specify Units	Write Amount	Write Amount	Write Amount, Specify Units	Write Amount	Write Amount
1. Dam water	____________	_____________	________Jerrycan	_______UGX/day	______________	_______Jerrycan	_______UGX/day
2. Surface water (rivers, lakes)	____________	_____________	________Jerrycan	_______UGX/day	______________	_______Jerrycan	_______UGX/day
3. Tap/piped water system	____________	_____________	________Jerrycan	_______UGX/day	______________	_______Jerrycan	_______UGX/day
4. Borehole with pump	____________	_____________	________Jerrycan	_______UGX/day	______________	_______Jerrycan	_______UGX/day
5. Dug well	____________	_____________	________Jerrycan	_______UGX/day	______________	_______Jerrycan	_______UGX/day
6. Rainwater harvesting	____________	_____________	________Jerrycan	_______UGX/day	______________	_______Jerrycan	_______UGX/day
7. Bottled Water	____________	_____________	________Jerrycan	_______UGX/day	______________	_______Jerrycan	_______UGX/day
8. Vendors	____________	_____________	________Jerrycan	_______UGX/day	______________	_______Jerrycan	_______UGX/day
9. Other: ___________	____________	_____________	________Jerrycan	_______UGX/day	______________	_______Jerrycan	_______UGX/day

5	**Management**	
5.1	Who fetches water for your household most of the time?	[1]Male [2]Female
5.1.1	Age	[years]
5.2	Who is primarily responsible for managing and maintaining your main drinking water source throughout the year? (***Do not read options***. *Multiple codes are possible, but should indicate main persons responsible*)	[0] No manager [1] Self [2] Village head/elder [3] Well manager [4] Community water management committee [5] Water bureau/Town Council Appointee [6] Non-governmental organization [-95] Other:________________________
5.4	The last time your primary drinking water source needed repairs, did you contribute?	[0] Did not contribute [1] Money [2] Labor [3] Materials [-95] Other:_______________
5.5	If you pay for your main drinking water sources, when (how often) do you pay?	[0] Do not pay [1] Annual fee [2] Monthly fee [3] Pay with each use [4] Only when repairs are needed [-95] Other:____________________

6	**Water Storage**	
6.1	Do you seal or cover the container during transport?	[0] Never [1] Sometimes [2] Always [-99] Does not apply
6.2	How often do you wash the largest water container in which you transport water?	[0] Never [1] Less than once a year [2] Yearly [3] Every six months [4] Monthly [5] Weekly [6] Every few days [7] Daily [8] Each use
6.3	Do you store water for more than a day at a time?	[0] No [1] Yes (*If yes, continue with following question.*)
6.3.1	Do you seal or cover the container during storage?	[0] Never [1] Sometimes [2] Always
6.4	How often do you wash your water containers in which you store water?	[0] Never [1] Less than once a year [2] Yearly [3] Every six months [4] Monthly [5] Weekly [6] Every few days [7] Daily [8] Each use [-99] Do not store
6.5	How do you wash your water storage containers? ***Do not read options.*** *Circle all that apply*	[0] Do not wash [1] Rinse with water [2] Scrub with brush and rinse [3] Use soap and scrubbing [4] Use ash [5] Use sand/soil [6] With leaves or plant material [7] With boiling water [-95] Other:________________ [-99] Do not store

7	**Water treatment**	
7.1	How safe do you think your primary drinking water is when you collect it at the source that you use (before in-house treatment, storage, and handling)? ***Read options aloud.***	[0] It is definitely not safe to drink [1] It is probably not safe to drink [2] I am not sure if it is safe to drink [3] It is probably safe to drink [4] It is definitely safe to drink [-99] Do not know
7.2	How safe do you think your water is at the time you actually drink it (after in-house treatment, storage, and handling)? ***Read options aloud***	[0] It is definitely not safe to drink [1] It is probably not safe to drink [2] I am not sure if it is safe to drink [3] It is probably safe to drink [4] It is definitely safe to drink [-99] Do not know
7.3	What are all the methods you use to make your water safer to drink? *(**Do not read options**; mark all that apply)*	[0] Do not treat [1] Boil [2] Simple Filter (e.g. Sieve through cloth, plastic net) [3] Advanced filter (e.g. ceramic) [4] Use chemicals (e.g. bleach/chlorine/coagulant etc.) [5] Defluoridization [-99] Do not know [-95] Other: ________________
7.3.1	(*If respondent indicated multiple forms of water treatment, ask*) What is the primary way you treat your drinking water?	[0] Do not treat [1] Boil [2] Simple Filter (e.g. Sieve through cloth, plastic net) [3] Advanced filter (e.g. ceramic) [4] Use chemicals (e.g. bleach/chlorine/coagulant etc.) [5] Defluoridization [-99] Do not know [-95] Other: ________________
7.4	Do you treat your water in both seasons, or only in the wet or dry season?	[0] Do not treat [1] Wet season [2] Dry season [3] Both seasons
7.5	In the seasons you treat water, how often do you treat your water?	[0] Do not treat [1] Each use [2] Daily [3] Weekly [4] Monthly [-95] Other________
7.6	Who answered the questions about water supply and water-related behaviors?	[1] Male head of household [2] Female head of household [3] Both [-95] Other:____________

8	**Rain Water Collection *(Only ask if answered yes to source 6, rainwater harvesting)***	
8.1	What do you use to collect Rain water? *Circle all that apply*	[1] Roof gutter into drum [2] Roof gutter into large storage tank [3] Small container under ridge of roof [4] Drum under ridge of roof [5] Container left outside in the open [-95] Other:___________________________
8.2	How long does a filled container last your household?	____________________________Time (Days) ________________Container Type
8.3	How much did this system cost to install?	____________________________ (Total Uganda Shillings) [-99] Do not know

9	**Sanitation**	
9.1	What kind of latrine does your household have? ***Do not read options***, *circle all that apply*	[1] No latrine [2] Pit latrine (ordinary) [3] VIP latrine (ventilated) [-95] Other________
9.1.1	If no latrine, what does the household use? ***Do not read options***, *circle all that apply*	[1] In the bush [2] In the yard [3] In an anthill [4] In a neighbor's latrine [5] In a public latrine [6] flush toilet
9.1.2	How many working latrines does your household have?	*Number of pit (ordinary) latrines* __________________________ *Number of VIP latrines* __________________________ *Number of other* __________________________
9.2	Do other people not in your household use your latrine on a regular basis? *If no, skip ahead to 9.3*	[0] No [1] Yes
9.2.1	If yes, do you rent? *If no, skip to 9.2.3*	[0] No [1] Yes
9.2.2	How many households do you share the latrine with?	_________________________ Number of households
9.2.3	Do you charge other people for the use of your latrine?	[0] No [1] Yes
9.2.4	How much do you charge?	Amount: __________ Time Period: [1] Per use [2] Day [3] Week [4] Fortnight [5] Month
9.3	When was your main latrine built?	*Number of years ago* __________________________ [-99] Do not know
9.3.1	Who built your main latrine?	[1] Household Member [2] Hired out [-95] Other ________ [-99] Do not know
9.3.2	How much did it cost for your latrine to be built?	*Total Ugandan Shillings* ___________________________ [-99] Do not know
9.3.3	How deep is the pit of the main latrine?	___________________________________ *include units* [-99] Do not know
9.3.4	How far away is the latrine from the main house?	___________________________________ *include units* [-99] Do not know
9.4	What do you do when your latrine becomes full?	[1]Self empty [2] Hire someone to empty by hand [3] Hire someone to empty by truck [4] Use ash to increase space [5] Cover and dig a new pit [-95] Other ___________________ [-99] Do not know
9.4.1	*If [1], [2], or [3] in 9.4* How much did it cost?	*Total Ugandan Shillings* ___________________________________
9.5	Overall, how satisfied are you with your latrine? ***Please read options aloud***.	[1] Not at all satisfied [4] Satisfied [2] Somewhat dissatisfied [5] Very Satisfied [3] Neutral

9.6	How do you dispose of rubbish? ***Do not read options**. Circle all that apply*	[1] Throw in yard [2] Throw in bush [3] Burn [4] Bury [5] Trash pit [6] Pay for trash collection [-95] Other _______________________
9.7	What materials do you use to clean yourself after pooping? ***Do not read options**. Circle all that apply*	[1] Toilet Paper [2] Paper [3] Leaves [4] Rocks [5] Water [6] Hand [-95] Other _____________________
9.8	How do you dispose of water used for household purposes (cleaning, washing, etc)? ***Do not read options**. Circle all that apply*	[1] Throw in yard [2] Throw in bush [3] Put in latrine [4] Bury/put in hole [-95] Other___________________________
9.9	Do you reuse any water?	[1] No [2] Yes

10	**Handwashing**	
10.1	Rate how frequently you wash your hands in the following situation	
	***Please read options aloud.** Units: [1] Never [2] Rarely [3] Sometimes [4] Mostly [5] Always [-99] Does not apply*	
	[1] After using toilet	[1] [2] [3] [4] [5]
	[2] Before preparing food	[1] [2] [3] [4] [5]
	[3] Before eating food	[1] [2] [3] [4] [5]
	[4] After eating food	[1] [2] [3] [4] [5]
	[5] After cleaning a child's bottom	[1] [2] [3] [4] [5] [-99]
	[6] When hands are visibly dirty	[1] [2] [3] [4] [5]
	[7] When praying	[1] [2] [3] [4] [5]
	[8] After handling animals	[1] [2] [3] [4] [5] [-99]
	[95] Other:________________________	[1] [2] [3] [4] [5]
10.2	What do you use to wash your hands ***Do not** read options and circle all that apply*	[1] Water [4] Banana Fiber [2] Soap [5] Soil [3] Ash [95] Other:________________
10.3	How much soap do you buy a week? ***Please read options aloud***	[0] No soap [4] More than one Bar of soap [1] A piece of soap [95] Other:_____________ [2] Half Bar of soap [-99] Do not know [3] One Bar of soap
10.4	Do you have a hand washing station?	[0] No [1] Yes

11	**Diarrhea Prevalence**									
	I am going to ask you some questions about diarrhea. Diarrhea is when you have 3 or more loose stools in 24 hours.									
Specify: Diarrhea is 3 or more loose stools in 24 hours. *Ask about all members in the household.*		11.1 Did [PID] have diarrhea during the past year?	11.2 Did [PID] have diarrhea during the past 7 days?	11.3 Did [PID] have diarrhea today?	11.3.1 Was there any blood/ mucus in the stool?	11.3.2 Was there also fever with this diarrhea episode	11.3.3 How many total combined days of work or school did [PID] miss because of this episode of diarrhea?	11.3.4 How many combined days of work or school did other members of the household miss because of [PID]'s diarrhea?	11.3.5 Did [PID] visit a doctor or trained community health worker regarding this illness?	11.3.6 How much total money was spent on treatment, including travel to health centers, tests, fees?
PID	List all household members names	[0] No [1] Yes [-99] Do not know	[0] No ***(Skip to next PID)*** [1] Yes ***(Continue)*** [-99] Do not know	[0] No [1] Yes [-99] Do not know	[0] No [1] Yes [-99] Do not know	[0] No [1] Yes [-99] Do not know	[Days]	[Days]	[0] No [1] Doctor [2] Other Health worker [-99] Do not know	[Shilling]
1		[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]			[0] [1] [2] [-99]	
2		[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]			[0] [1] [2] [-99]	
3		[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]			[0] [1] [2] [-99]	
4		[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]			[0] [1] [2] [-99]	
5		[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]			[0] [1] [2] [-99]	
6		[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]			[0] [1] [2] [-99]	
7		[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]			[0] [1] [2] [-99]	
8		[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]			[0] [1] [2] [-99]	
9		[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]			[0] [1] [2] [-99]	
10		[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]	[0] [1] [-99]			[0] [1] [2] [-99]	

	Diarrhea Continued: ***If a household member has had diarrhea, please fill out the following***		
	PID#	Age	Gender
	______________________________	____________________________ years	[1] Male [2] Female
	______________________________	____________________________ years	[1] Male [2] Female
	______________________________	____________________________ years	[1] Male [2] Female
	______________________________	____________________________ years	[1] Male [2] Female
	______________________________	____________________________ years	[1] Male [2] Female

E. Bacteriological Results of Water Samples

		Household Point-of-Use Sample TTC Count				Turbidity		
Village	Number of Samples Taken	Average	Min	Max	StdDev	Average	Min	Max
Kitwe Kyambogo	13	3017.69	25	10500	3739.79	2.85	0.41	7.97
Kyabachwezi	4	593.75	0	1300	601.52	14.28	3.40	30.10
Kyakala	9	2784.44	0	8100	3156.57	14.64	1.69	63
Kyangogola	1	5000	5000	5000	n/a	7.94	7.94	7.94
Migeera A	11	1758.26	0	5000	2140.09	20.45	0.66	109.00
Migeera B	22	1912.17	0	7275	2429.17	8.64	0	60
Nalukonge	1	2100	2100	2100	n/a	189	189	189

F. Full Chemical Analysis of Water Samples

a. Duke team's sampling protocol

For wells and boreholes:

Important - Take sample as close to the point of source as possible, avoid potential contamination from storage tanks and piping system

1. Let the water run for 10 minutes, if it has not been recently pumped, again to ensure an accurate sampling of the groundwater constituents
2. While water is running, place bucket underneath spout (having removed any hose or funneling apparatus that might have been attached to the tap.
3. Place EC and ORP probe in bucket
4. Line up bottles and label each with site ID using a permanent marker. Also, label the gallon Ziploc bag that will hold the samples upon completion.
5. Unwrap syringe, unwrap and attach filter
6. Remove plunger from syringe, fill with water directly from the tap.
7. Replace plunger and gently push water through filter into an open sampling bottle. Repeat until bottle is full for the bottle with yellow, red/yellow labels, red, and large green (list given in order of importance).
8. At this time, or have someone else perform after 10 minutes have elapsed, record probe readings in field measurement book for Temperature, pH, and EC. Making sure that the readings have had enough time to stabilize.
9. Once the Temperature has been measured, input that value into the ORP probe and give time to stabilize on one value.

10. For the small green and the red/black bottles, submerge in bucket full of water, moving it around in an attempt to eliminate any air bubbles that might be stuck to the sides of the bottle or lid.
11. In the event that the filter becomes clogged and very little water is escaping through the filter tip, open a new sealed filter and replace previous one. Should all filters be used up in the process of sampling, prioritizing the bottles will ensure that the most important samples for testing are filtered by order of importance. However, in the case of extremely dirty or turbid water, make sure to label the unfiltered bottles, so the samples can be filtered back at the lab.

For surface water:

1. Submerge bucket in water, retrieving water below 30 cm depth.
2. Place EC and ORP probe in bucket
3. Line up bottles and label each with site ID using a permanent marker. Also, label the gallon Ziploc bag that will hold the samples upon completion.
4. Unwrap syringe, unwrap and attach filter
5. Remove plunger from syringe, fill with water directly from the bucket, either pouring it in or submerging the syringe.
6. Replace plunger and gently push water through filter into an open sampling bottle. Repeat until bottle is full for the bottle with yellow, red/yellow labels, red, and large green (list given in order of importance).
7. At this time, record probe readings in field measurement book for temperature, pH, and EC. Making sure that the equipment has had enough time to stabilize and shows clear readings.
8. Once the temperature has been measured, input that value into the ORP probe and begin to swirl the probe in circular motions in the bucket, giving it instrument time to stabilize. Record the show value.
9. For the small green and the red/black bottles, submerge in bucket full of water, moving it around in an attempt to eliminate any air bubbles that might be stuck to the sides of the bottle or lid.
10. In the event that the filter becomes clogged and very little water is escaping through the filter tip, open a new sealed filter and replace previous one. Should all filters be used up in the process of sampling, prioritizing the bottles will ensure that the most important samples for testing are filtered. However, in the case of extremely dirty or turbid water, make sure to label the unfiltered bottles, so the samples can be filtered back at the lab.

b. Chemical Results

			IC Data (mg/L)					DCP Data (mg/L)							
ID	Sample Name	Source	F	Cl	Br	NO3	SO4	Ca	Mg	Sr	Na	Fe	Ba	Mn	Si
1	S-WALU002	GW	0.361	47.497	0.069	0.010	70.583	100.354	30.010	0.287	30.408	0.000	0.040	0.711	32.083
2	CALUTAP001	GW	1.390	8.683	0.034	1.997	15.271	44.880	22.049	0.248	32.499	0.033	0.087	0.312	26.464
3	S-MIGA002	SW	0.219	4.598	0.000	3.591	1.585	11.026	2.089	0.077	6.602	0.830	0.040	0.413	5.459
4	S-WALUK001	GW	3.309	9.205	0.000	0.037	20.791	47.423	13.812	0.267	37.855	1.195	0.109	0.251	31.864
5	S-RW001	RW	0.029	3.288	0.000	5.594	4.794	3.611	0.599	0.022	1.622	0.012	0.006	0.044	0.477
6	S-KWI001	GW	0.309	48.806	0.089	13.691	33.721	42.750	24.944	0.171	21.700	0.275	0.024	0.028	30.111
7	BHCAL002	GW	1.125	8.769	0.039	0.000	12.202	45.807	21.239	0.243	33.420	0.262	0.091	0.312	27.315
8	S-KYAK006	GW	0.488	10.842	0.026	3.921	5.327	23.156	14.060	0.296	27.126	0.000	0.137	0.079	40.315
9	S-UWESO001	GW	0.261	2.683	0.000	0.989	8.026	39.185	14.368	0.227	17.782	0.028	0.048	0.044	43.302
10	S-MSTAP	GW	0.223	2.895	0.000	1.325	8.009	40.248	13.579	0.218	17.053	0.011	0.042	0.011	41.395
11	S-KYAK005	SW	0.492	2.994	0.000	4.590	0.142	6.446	2.966	0.060	7.516	0.719	0.029	0.081	3.210
12	S-KYAK001	GW	0.482	11.022	0.000	5.428	5.141	22.335	12.910	0.264	24.663	0.632	0.128	0.027	37.884
13	S-KYAM001	GW	0.914	7.526	0.047	0.018	5.586	59.502	24.444	0.257	32.357	0.412	0.036	0.164	34.446
14	S-MIG001	SW	0.223	4.159	0.000	0.469	1.907	9.063	1.697	0.060	5.028	0.750	0.047	0.416	4.925
15	S-KYAB001	GW	0.310	16.047	0.031	5.642	15.998	22.623	10.581	0.161	31.905	0.814	0.024	0.016	40.368
16	S-RW002	RW	0.000	0.572	0.000	0.000	0.506	2.066	0.300	0.013	0.536	0.017	0.004	0.020	0.268
17	S-NAL001	GW	0.473	7.444	0.020	11.927	4.420	26.552	11.235	0.183	14.447	0.010	0.046	0.007	42.871
18	S-UWESOTAP002	GW	0.174	2.676	0.000	0.000	7.849	43.112	14.290	0.208	16.985	0.004	0.052	0.015	41.011
19	S-KYAB002	GW	0.432	15.672	0.031	5.504	15.965	21.940	10.817	0.158	31.113	1.114	0.023	0.020	39.040
20	S-KYAB003	GW	0.395	15.708	0.031	7.135	15.923	22.560	11.092	0.160	31.271	1.273	0.023	0.032	38.291
21	S-MIGB010	GW	1.320	8.649	0.000	0.000	13.481	47.063	20.769	0.211	31.067	0.016	0.085	0.300	25.160
22	S-NAB001	GW	1.020	18.920	0.056	4.285	33.920	39.136	19.543	0.324	36.227	0.016	0.071	0.045	37.297
23	S-KYAK002	SW	0.386	2.563	0.000	0.500	1.955	6.086	2.790	0.056	6.400	1.163	0.020	0.097	4.041
24	S-WAL001	GW	0.356	46.979	0.059	0.024	76.275	90.304	27.872	0.232	29.213	0.008	0.029	0.578	29.141
25	S-KIT003	GW	0.312	49.370	0.080	13.814	33.942	40.655	23.239	0.164	20.002	0.272	0.022	0.015	28.224

ICP-MS Results (ppb)

ID	Li	Be	B	Mg	Al	Ca	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
1	45.073	0.161	13.009	17858.86	3.666	98128.93	0.373	0.882	538.417	6236.028	0.594	1.287	0.46	13.617
2	81.79	0.518	11.109	17786.49	4.471	43343.84	0.327	0.397	275.242	62.743	0.307	0.745	0.42	255.15
3	0.454	0.019	11.621	1784	537.475	10119.24	1.088	0.527	401.327	464.001	0.837	1.117	0.585	4.416
4	83.881	0.472	30.585	13901.33	5.256	49654.38	0.282	0.4	240.035	670.112	0.084	0.72	0.16	1875.953
5	0.588	0.062	36.236	537.53	15.185	3432.09	0.951	0.39	39.517	15.217	0.419	1.084	4.255	52.248
6	38.307	0.119	7.342	24723.14	2.753	40456.43	6.729	1.911	18.654	184.24	0.089	1.259	2.477	440.57
7	76.503	0.748	10.739	19809.69	3.5	42964.99	0.23	0.45	267.598	174.777	0.069	0.638	0.172	39.695
8	46.088	0.052	4.353	12750.07	5.152	18007.15	1.055	0.355	60.523	2680.246	0.527	3.213	0.444	825.409
9	21.966	0.073	12.119	14661.98	3.918	40005.85	6.093	0.551	34.381	46.941	0.032	1.94	0.959	19.302
10	22.377	0.04	11.758	13356.04	1.389	40258.42	4.994	0.504	0.638	42.984	0.032	1.121	2.368	34.234
11	0.261	0.027	11.522	2411.8	347.637	5579.04	2.161	0.453	73.806	384.704	0.615	1.43	1.725	1.045
12	47.451	0.066	4.304	13025.39	2.707	18732.34	1.698	0.323	19.771	365.274	0.127	2.175	1.38	846.258
13	70.923	0.163	10.442	20106.84	3.269	60454.65	1.994	0.279	141.987	311.208	0.127	1.087	2.609	1172.014
14	0.456	0.052	10.27	1473.47	730.734	8479.33	1.135	0.521	433.571	442.259	1.21	1.276	1.199	6.828
15	22.844	0.279	5.05	10691.01	2.989	20802.86	2.004	0.388	10.04	510.394	0.037	1.277	1.168	45.293
16	0.201	0	2.551	302.33	12.3	2136.52	0.437	0.286	19.897	8.203	11.524	0.748	3.573	51.604
17	16.2	0.081	7.347	12110.53	3.547	26921.84	9.431	0.339	1.032	29.355	0.046	1.66	0.715	98.263
18	22.996	0.006	11.651	14435.1	3.443	41346.51	3.605	0.166	13.78	55.258	0.204	5.38	199.64	4878.971
19	24.064	0.273	5.46	11122.32	4.017	21279.31	1.461	0.398	17.887	749.514	0.131	1.808	0.325	48.903
20	23.333	0.248	4.671	10480.67	4.193	20072.16	0.957	0.337	27.675	797.177	0.191	2.41	0.397	49.497
21	84.37	0.679	11.123	21304.6	3.085	44766.51	0.192	0.337	282.834	50.722	0.028	0.618	0.052	92.622
22	46.714	0.054	151.161	19672.47	3.462	37540.95	0.616	0.564	38.069	52.167	0.059	1.456	0.143	268.445
23	0.621	0.09	11.224	2539.8	623.426	5886.78	2.581	0.649	94.521	693.192	0.783	1.697	1.734	5.903
24	44.384	0.019	12.283	23283.21	1.26	94033.18	0.377	1.129	548.908	468.859	0.688	1.321	0.463	3.372
25	33.903	0.119	6.333	23949.17	3.687	38426.72	7.103	1.674	13.377	179.901	0.062	1.159	2.442	271.906

ID	As	Se	Rb	Sr	Mo	Ag	Cd	Sb	Ba	Tl	Pb	Th	U
1	25.74	0.565	0.474	254.2	1.268	0.003	0.01	0.088	32.952	0.009	0.022	0.319	0.122
2	0.979	0.322	1.987	228.795	12.486	0.004	0.019	0.089	74.277	0.009	0.448	0.12	0.649
3	0.635	0.438	12.788	80.28	0.442	0.004	0.009	0.08	40.497	0.014	0.386	0.148	0.115
4	1.584	0.37	2.67	266.974	9.067	0.007	0.044	0.074	100.853	0.005	0.992	0.147	0.123
5	0.211	0.619	2.476	21.264	0.194	0.003	0.038	0.2	8.192	0.026	0.193	0.068	0.048
6	9.925	1.613	2.282	162.741	0.752	0.004	0.047	0.241	23.596	0.003	0.127	0.081	6.11
7	1.365	0.086	1.955	221.778	13.017	0.004	0.017	0.08	79.619	0.001	0.701	0.081	0.363
8	0.104	0.488	1.447	260.832	0.804	0.003	0.015	0.109	115.93	0.001	0.052	0.089	1.014
9	0.612	0.527	0.939	230.176	0.716	0.003	0.014	0.051	45.98	0	0.043	0.058	2.574
10	0.664	0.23	1.047	219.285	0.573	0.003	0.01	0.052	39.342	0	0.272	0.046	2.377
11	1.209	0.178	7.571	55.592	0.442	0.004	0.004	0.072	29.624	0.013	0.976	0.119	0.192
12	0.042	0.681	1.413	270.462	0.399	0.002	0.018	0.059	125.028	0	0.178	0.056	1.037
13	0.137	0.319	2.552	245.952	2.123	0.002	0.097	0.106	31.314	0.007	0.381	0.055	38.379
14	0.539	0.278	12.317	66.197	0.038	0.002	0.025	0.058	48.602	0.028	0.915	0.158	0.189
15	0.054	0.436	2.267	169.51	2.388	0.002	0.016	0.042	23.05	0	0.02	0.047	5.744
16	0.191	0.257	1.534	12.444	0.112	0	0.017	0.082	5.427	0.002	0.062	0.04	0.023
17	0.403	0.403	0.312	209.19	1.145	0	0.018	0.046	49.125	0	0.138	0.037	2.193
18	0.301	0.475	0.925	229.844	0.426	0.01	1.132	0.183	49.144	0	18.617	0.033	1.94
19	0.183	0.447	2.198	166.361	2.353	0.002	0.016	0.046	21.981	0	0	0.103	5.544
20	0.21	0.441	2.194	161.278	2.252	0.002	0.011	0.059	21.473	0	0.019	0.074	5.238
21	1.155	0.611	1.941	228.027	12.818	0	0.012	0.044	79.423	0	0.343	0.063	0.322
22	0.063	0.645	1.47	384.655	4.131	0.002	0.105	0.076	65.708	0	0	0.058	6.841
23	1.287	0.505	7.606	55.468	0.347	0.004	0.012	0.081	22.015	0.013	1.294	0.157	0.188
24	7.139	0.698	0.616	246.448	0.924	0.001	0.004	0.062	26.902	0.001	0	0.053	0.109
25	9.746	1.436	2.165	158.924	0.631	0.001	0.045	0.127	22.12	0	0.098	0.046	5.779

G. Kampala Water Testing Results

Sample ID (mg/L)	Village	pH	Alkalinity	Ca	Bi-carbonate	F	Fe	As	Salinity	Al
S-KYAL001	Kyakala	7.1	144	22	176	0	0.1	<0.01	0.1	-
BHCAL003	CALU BH	7.4	272	40	332	0	0.2	<0.01	0.2	0.01
S-UWESH	UWESO BH	6.9	188	34	229	0	0	<0.01	0.2	-
KITBH002	KITWE	6.9	148	43	180	0	0	<0.01	0.2	-
S-KYAB001	KYABACHWEZI	7.2	128	20.8	156	0	0.1	<0.01	0.1	-
S-MIGB010	MIGEERA B	7.4	240	44.8	292	0	0	<0.01	0.2	-

H. WHO Recommended Water Treatment for Bacterial Contamination

Organism	Temperature (°C)	Inactivation time(s)	Log_{10} reduction	Reference
BACTERIA				
Campylobacter spp.	60	300	3.9 log	D'Aoust et al. (1988)
	63	300	> 5 log	D'Aoust et al. (1988)
	60	8.2	Per log	Sörqvist (2003)
	62	15	3.5–5 log	Juffs & Deeth (2007)
Coxiella burnetii	79.4	25	No survivors	Juffs & Deeth (2007)
Escherichia coli	60	1 800	6 log	Moce-Llivina et al. (2003)
	65	< 2	Per log	Spinks et al. (2006)
	72	0.4	Per log	Sörqvist et al. (2003)
Escherichia coli 0157	60	300	1.5 log	D'Aoust et al. (1988)
	64.5	300	> 5 log	D'Aoust et al. (1988)
	65	3	Per log	Spinks et al. (2006)
	62	15	< 1–5 log	Juffs & Deeth (2007)
Enterococcus faecalis	65	7–19	Per log	Spinks et al. (2006)
Klebsiella pneumoniae	72	23	Per log	Sörqvist (2003)
	65	< 2	Per log	Spinks et al. (2006)
Legionella pneumophila	58	360	Per log	Dennis, Green & Jones (1984)
Legionella spp.	80	18–42	Per log	Stout, Best & Yu (1986)
Mycobacterium paratuberculosis	72	15	> 4 log	Juffs & Deeth (2007)
Pseudomonas aeruginosa	65	5	Per log	Spinks et al. (2006)
Salmonella typhimurium	65	< 2	Per log	Spinks et al. (2006)
Salmonella choleraesuis[a]	60	300	Per log[b]	Moce-Llivina et al. (2003)
Salmonella spp. except *Salmonella seftenberg*	72	0.1	Per log	Sörqvist (2003)
Salmonella seftenberg	60	340	Per log	Sörqvist (2003)
Serratia marcescens	65	< 2	Per log	Spinks et al. (2006)
Shigella sonnei	65	3	Per log	Spinks et al. (2006)
Vibrio cholerae	55	22.5	Per log	Johnston & Brown (2002)
	70	120	> 7 log	Johnston & Brown (2002)
Yersinia enterocolitica	64.5	300	> 5 log	D'Aoust et al. (1988)
	72	0.5	Per log	Sörqvist (2003)

VIRUSES				
Adenovirus 5	70	1 260	> 8 log	Maheshwari et al. (2004)
Coxsackievirus B4	60	1 800	5.1 log	Moce-Llivina et al. (2003)
Coxsackievirus B5	60	1 800	4.8 log	Moce-Llivina et al. (2003)
Echovirus 6	60	1 800	4.3 log	Moce-Llivina et al. (2003)
Enteroviruses	60	1 800	4.3 log	Moce-Llivina et al. (2003)
Hepatitis A	65	120	2 log	Parry & Mortimer (1984)
	65	1 320	3 log	Bidawid et al. (2000)
	75	30	5 log	Parry & Mortimer (1984)
	80	5	5 log	Parry & Mortimer (1984)
	85	< 30	5 log	Bidawid et al. (2000)
	85	< 1	5 log	Parry & Mortimer (1984)
Poliovirus 1	60	1 800	5.4 log	Moce-Llivina et al. (2003)
	62	1 800	> 5 log	Strazynski, Kramer & Becker (2002)
	72	30	> 5 log	Strazynski, Kramer & Becker (2002)
	95	15	> 5 log	Strazynski, Kramer & Becker (2002)

PROTOZOA				
Cryptosporidium parvum	60	300	3.4 log	Fayer (1994)
	72	60	3.7 log	Fayer (1994)
	72	5–15	> 3 log	Harp et al. (1996)
Giardia	56	600	> 2 log[c]	Sauch et al. (1991)
	70	600	> 2 log[d]	Ongerth et al. (1989)

[a] Now known as *Salmonella enterica*.
[b] The log reductions were calculated from the results presented in Moce-Llivina et al. (2003).
[c] The log reductions were calculated from the results presented in Sauch et al. (1991).
[d] The log reductions were calculated from the results presented in Ongerth et al. (1989).

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