Analyzing the Connections Among Water Access, Sanitation, Malaria and Diarrhea Outcomes in Rural Central Uganda

Undergraduate Honors Thesis in Global Health
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I. Abstract

Access to safe water and sanitation around the world has increased significantly in the past few decades. The United Nations claims that 91% of the world's population has access to safe water, exceeding the Millennium Development Goal for water access. Yet, some evidence in the literature suggests that safe water and sanitation access is overestimated, as the common indicator used to estimate safe water is infrastructural. The usage of water, behaviors surrounding water acquisition and storage, and possible contamination along the source to point-of-use continuum is poorly understood.

This cross-sectional epidemiological study used a combination of surveying, mapping and bacteriological water testing to identify some of the possible factors in water contamination, and relationships with malaria and diarrhea burden, in a parish in Central Uganda. Secondary goals included assessing the burden of malaria and diarrhea in the parish, and assessing the use of mapping and water testing as field research tools. The survey included questions on water acquisition and usage behavior, sanitary conditions, knowledge of diarrhea, and malaria and diarrhea burden. In this parish, 126 households across 9 villages were randomly chosen to be surveyed, mapped and water tested. All water sources in the parish were additionally mapped and water tested.

Across all water sources, including piped water, the water quality at the household point-of-use level was drastically worse than quality measured at the source. In fact, among all water sources, piped water recipients showed the highest average bacterial loads, despite the clean quality of the source itself. Possible factors in lowering or raising contamination, as displayed by regression results, include the frequency of obtaining water and distance from the water source respectively. The malaria and diarrhea case sample size proved smaller than expected, and challenges remain in using mapping and water testing in the field.

These results support the theories that the amount of people with access to safe water is overestimated, and that contamination exists along the source to point-of-use continuum. More research is needed to investigate the exact points of contamination in the spectrum and possible contaminating factors.

II. Preface

I started this project after applying for, and being accepted into, the Duke Global Health Institute's Summer Research Training Program Uganda site for 2014. I came to Duke broadly interested in infectious diseases, and wanting to participate in some sort of fieldwork research-based experiential learning opportunity. I applied to the Uganda site because this program allowed me to carry out independent research and gain epidemiological experience, which is what I am academically interested in. At the time I thought I signed up for "only" a summer experience; I did not realize then that my work would carry-over into a multi-year experience, encompassing independent studies, theses writing and mentorship opportunities.

Duke University's involvement in this community in Central Uganda originally began as mainly a service program, but over the years the program developed into a comprehensive community-based participatory research program. Safe water and sanitation was first incorporated into the program in 2010, and malaria in 2013. Service, however, remains an integral part of the partnership, with community health fairs and a group counseling program being held every year.

The overall goal of the community partnership is to improve the health of the local community, and this study on assessing the determinants of communicable diseases takes place within the overall framework of the community partnership, along with research on maternal and child health and non-communicable diseases. This project assesses the states of water and sanitation in the parish, and uses this framework to investigate malaria and diarrhea prevalence, as both diseases are predicated in part on water and sanitation factors, using self-reported surveys as well as objective water testing and mapping.

III. Introduction

Access to clean and safe water has increased tremendously in recent decades. The WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation (JMP) estimates that, as of 2015, 91% of the world's population has access to improved sources of drinking water, with improved water sources defined as boreholes and piped water("WHO | Progress on sanitation and drinking water," n.d.). The JMP additionally estimates that 68% of the world's population is using private and improved sanitation facilities, defining such facilities as flush toilets and improved (with slab) pit latrines("WHO | Progress on sanitation and drinking water," n.d.). 2.4 billion people still lack access to such facilities.

The JMP provides country-level estimates as well. In Uganda, across the entire country, an estimated 79% use improved sources of drinking water (with 5% of that using piped water), and 19% improved sanitation facilities("WHO | Progress on sanitation and drinking water," n.d.).

However, these estimates are based on infrastructural statistics, and defined by the spread of physical infrastructure improvements. In a separate analysis that includes bacterial testing, Bain et al. estimate that 1.8 billion people, or around three times the JMP number, are using contaminated sources of drinking water globally(Bain et al., 2014). Thus, it is likely that the JMP's sanitation estimates and country level estimates are overly optimistic as well.

Water, and access to water, is a major indicator and determinant of standards of living. In particular, water, and variations in water access and quality, can influence the spread of infectious diseases. Many common diseases found throughout the developing world, such as cholera and schistosomiasis, are water-borne. Conversely, safe drinking water and proper management of water resources reduces the risk of contracting both water-borne and vector-borne diseases such as malaria.

Diarrhea and malaria remain among the top causes of morbidity and mortality, both around the world and in Uganda. Diarrheal diseases such as cholera are caused by vectors that are water-borne, and malaria spread is accentuated in part by the availability of standing water and water-rich environments(Keiser, Singer, & Utzinger, 2005). According to the World Health Organization, diarrheal diseases is the 7th leading cause of death among all age groups, with an estimated 1.7 billion cases and 1.5 million mortalities every year(“WHO | The top 10 causes of death,” n.d.)(“WHO | Diarrhoeal disease,” n.d.). Among children under 5, diarrhea is the 2nd leading cause of death(“WHO | Diarrhoeal disease,” n.d.). Malaria remains the 3rd top cause of death among post-natal children around the world(“WHO | Causes of child mortality,” n.d.). An estimated 3.2 billion people, around half of the world’s population, are at risk of malaria(“WHO | Malaria,” n.d.).

In Uganda, diarrhea is the 8th leading cause of death overall and the top cause among children under-5(“GBD Compare | IHME Viz Hub,” n.d.). Malaria is the 2nd leading cause of morbidity and mortality in Uganda, with an estimated 3.6 million cases and 6000 deaths per year(“WHO | World Malaria Report 2015,” n.d.).

As a benchmark for measuring progress against health and other developmental challenges, including malaria and diarrhea prevalence and the availability of safe water, the Millennium Development Goals were a set of goals adopted by the United Nations in 2000, for attainment by 2015. Target 6.C specifies to “have halted by 2015 and begun to reverse the incidence of malaria and other major diseases”(“United Nations Millennium Development Goals,” n.d.-a). Target 7.C specifies to “halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation(“United Nations Millennium Development Goals,” n.d.-b). Per the JMP, which uses an infrastructural definition of water safety, the water aspect of MDG 7.C was met and surpassed in 2010, however, none of the other goals were met. The Sustainable Development Goals, adopted in 2015 by the United Nations, aim to set the development agenda for the next 15 years. Goal 6 aims to “ensure access to water and sanitation for all”; specific targets include to “achieve universal and equitable access to safe and affordable drinking water for all” and to “achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations” by 2030(Nino, n.d.). Goal 3 aims to “ensure healthy lives and promote well-being for all at all ages”; specific targets include “by 2030, end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases”(Nino, n.d.). No specifics are provided for how to obtain these goals.

The Government of Uganda promotes the expansion of piped water through the government-owned and for-profit National Water and Sewerage Corporation. Water and sanitation resource planning on a broad level is undertaken by district-level governments, however, construction of household facilities and behaviors is a household and personal decision. Generally speaking, in areas without piped water access or expansion, the construction of boreholes is the preferred method, as boreholes are categorized as an improved source of water, and borehole expansion is listed in the district five-year development plan. To combat malaria specifically in Uganda, the national government in 2007 adopted a policy of universal, free distribution of long-lasting insecticide-treated bed nets to combat the spread of malaria, for all households and age groups. Indoor-residual spraying is available in some areas of the country, and as a policy, artemisinin-based combination therapy is the standard, free treatment option for malaria cases(“WHO | World Malaria Report 2015,” n.d.).

This project aims to discover and describe the water and sanitation access and practices that can help inform and support health professionals working to reduce the burden of diarrheal diseases and malaria, in a rural parish of Central Uganda. Despite the conclusions of the JMP, a growing amount of research suggests that water sources that are assumed to be improved are, in fact, contaminated(Bain et al., 2014), and the determinants and situations of household storage of water are poorly understood(Wright, Gundry, & Conroy, 2004), both generally and in Uganda. This study, which incorporates survey, GPS data and water-testing data, is the first comprehensive water study in this parish. As part of the comprehensive community partnership, the ultimate goal is to improve the health of residents of the parish by identifying and addressing the specific determinants of communicable diseases.

IV. Background

The WHO/UNICEF Joint Monitoring Program for Water and Sanitation (JMP) was established in 1990 to measure progress against MDG 7, and now SDG 6("WHO | Progress on sanitation and drinking water," n.d.). JMP measures progress against the MDGs and SDGs with the "percentage of population using safely managed drinking-water services" and "percentage of population using safely managed sanitation services" indicators, part of the WHO Global Reference List of 100 Core Health Indicators("WHO | Global Reference List of 100 Core Health Indicators, 2015," n.d.). Per the JMP, improved sources of drinking water include piped water (private or shared), boreholes, rainwater and protected wells and springs; unimproved sources include unprotected springs, carts, tanker-trucks, surface water and exclusively bottled water. Improved sources of sanitation include flush toilets, piped sewer systems, septic tanks, and pit latrines with slabs; unimproved facilities include pit latrines without slabs, any sanitation facility that is shared, and open defecation("WHO | Progress on sanitation and drinking water," n.d.).

However, measures and indicators of development and health used by the JMP and other broad statistics gathering efforts such as the national Demographic and Health Surveys are generally infrastructure-based. The internationally-used indicators for water safety and prevalence are infrastructural. The JMP considers the prevalent of improved water sources to be a measure of the proportion of the population using safe water. This measure assumes that all boreholes and piped water systems are built to a good standard. Improved water sources, such as boreholes and piped water, are assumed to be both better than unimproved water sources, and conforming to WHO standards for safety, both at the source and at the point-of-use. Thus, by using infrastructural indicators as a measure of access to and use of water, the assumption is that no contamination exists between source and point-of-use(Bain et al., 2014).

Piped water systems are designed so that large-scale water storage is kept to a minimum, as water storage increases so does the likelihood of contamination(Wolf et al., 2014). Thus, piped water users are assumed to use piped water on an on-demand basis, and not store it for extended periods of time. Additionally, populations living in areas with improved water sources such as piped water, are assumed to be using exclusively those improved water sources(Wolf et al., 2014).

Thus, a large number of assumptions need to be met for the JMP's infrastructural premise to hold true, yet evidence exists that some of these assumptions are unfounded(Bain et al., 2014). Improved sources of water may not be built to the same high standard, or some form of contamination may happen along the source to point-of-use continuum that negates the effects of having safe sources of water(Wolf et al., 2014). Bacteriologically, WHO's Guidelines for Drinking Water quality specify that for water to be considered safe, *Escherichia coli* or Coliform bacteria should not be detectable (0ml) in a 100ml sample of water. Using this definition, in a systematic review and meta-analysis, Bain et al. found extensive contamination in both urban piped water supplies and boreholes, in addition to "unimproved" water sources such as unprotected groundwater sources. Using new modeling techniques and extrapolating from this data, they concluded that 1.8 billion people globally use a contaminated source of drinking water, of which 1.1 billion use drinking water of moderate risk (>10 colonies/100ml), and that at least 10% of improved water sources were at high risk (>100 colonies/100ml) of contamination(Bain et al., 2014).

In another systematic review, Shields et al. found that the possibility of fecal contamination of water increased dramatically from source water to household stored water. The authors hypothesize that steps in the transportation of water and in the household storage of water, and contact with dirty hands and/or utensils, could lead to this increase. The authors differentiate piped water into "improved" and "unimproved" piped water, with the latter characterized by an inconsistent or intermittent supply and the lack of residual chlorine. The Shields et al. study, however, contrasts source water with household stored water, and does not further specify whether the household water is pre or post-treatment or point-of-use(Shields, Bain, Cronk, Wright, & Bartram, 2015).

Both the Bain and Shields studies were published after the project study period in the summer of 2014, thus none of the information in either study was available or consisted during the project design and implementation phase.

For all water sources, regardless of water source type, household point-of-use water should be safer than source water if households indicate that they are using a point-of-use intervention such as boiling. There is some evidence, however, that households using piped water could spend less time boiling or otherwise use boiling inadequately, owing to the perceived safety of piped water(Parker Fiebelkorn et al., 2012). Additionally, on sanitation surveys, if residents indicate that they clean their water storage containers, they are assumed to be cleaning those containers thoroughly and with appropriate detergents(Parker Fiebelkorn et al., 2012).

Within the household, it is unlikely that residents leave standing pools of water available in uncovered containers for extended periods of time, thus it is unlikely that containers within the household could facilitate mosquito breeding. However, despite this, outside standing water and general water sanitation practices could increase the risk of mosquito breeding, and hence, malaria. Despite significant reductions in malaria incidence, malaria remains a top cause of morbidity and mortality across all age groups, both around the world and in Uganda. Malaria is prevalent in 97 countries and territories around the world("WHO | Malaria," n.d.). The World Health Organization estimates that 6.2 million malaria deaths have been averted between 2000 and 2015, that the incidence rate has fallen by 37% and that the mortality rate has decreased by 58%(Wanzira et al., 2014). In Uganda, however, malaria remains endemic, and while the Government of Uganda's National Malaria Control Program adopted the goal of universal coverage of long-lasting insecticide treated nets (LLINs) in 2007, ownership of nets across the country remains low at an estimated 46%(Wanzira et al., 2014).

Malaria is caused by the *Plasmodium* vector that is transmitted by female *Anopheles* mosquitos. In Uganda, the *Plasmodium falciparum* vector is dominant, and it is carried by both *Anopheles gambiae* and *Anopheles funestus* mosquitos(“WHO | World Malaria Report 2015,” n.d.). The disease manifests itself as an acute febrile illness, with symptoms appearing 7-15 days after the infective mosquito bite. Symptoms include fever, headache, chills, and vomiting. Children with severe malaria can also develop anemia, respiratory distress or multi-organ involvement(“WHO | Malaria,” n.d.).

All *Anopheles* mosquitos bite between dusk and dawn. *Anopheles* mosquitos lay their eggs in water, and the females seek a blood meal in part to feed their eggs. Different species of *Anopheles* mosquitos prefer different aquatic habitats for reproduction, but most African species have long lifespans and a preference for human biting. Transmission is moderated by seasonal affects, with the highest transmission rates occurring during and after rainy seasons(“WHO | Malaria,” n.d.).

The gold standard treatment option for malaria cases is artemisinin-based combination therapy (ACT)(“WHO | Malaria,” n.d.). The Government of Uganda adopted ACT as the preferred and freely available treatment option in 2005; LLIN distribution for households with pregnant women and children began in 2010, and universal distribution in 2013, both starting in the Central Region.

Prevention strategies concentrate on vector control, and in particular the use of long-lasting insecticidal nets. WHO recommends universal distribution of LLINs as the most effective and cost-effective measurement of controlling malaria. However, the efficacy of LLINs is predicated on its proper usage. LLINs are only effective if there are enough for every member of each household (two people or less to one bed net). The bed nets must be tied to a wall or ceiling and completely covering a bed, and they must be used every night during the entire night. Thus, the assumption that bed nets are effective at preventing malaria is predicated on the proper use of those bed nets.

The causes of most diarrheal diseases are water-borne agents, such as the *Escherichia coli* and *Vibrio cholerae* bacteria, thus poor water quality is directly linked to diarrheal incidence. Diarrhea remains a top cause of morbidity and mortality across the world, particularly with children under five. WHO estimates that there are 1.7 billion cases, and 760000 fatalities, attributable to diarrhea every year. As diarrhea is the effluent of fluids and salts, the immediate cause of fatality from diarrhea is severe dehydration. Malnourished or immunocompromised children are thus especially at risk from diarrhea(“WHO | Diarrhoeal disease,” n.d.).

Symptomatically, diarrhea is defined by the passage of three or more loose or liquid stools per day. WHO defines three clinical types of diarrhea: acute watery diarrhea, acute bloody diarrhea, and persistent diarrhea. Diarrhea is often accompanied by dehydration, the symptoms of which include thirst, restless behaviors, sunken eyes, shock and decreased skin elasticity(“WHO | Diarrhoeal disease,” n.d.).

Diarrhea is most commonly caused by bacterial, viral and parasitic organisms, most of which are water-borne. Thus, faecally contaminated water is the primary method of transmission and infection. Rotavirus and *Escherichia coli* are the two causal agents of diarrhea most commonly found in developing countries.

Diarrhea can also be spread from person-to-person, or from food stored in unhygienic or polluted conditions(“WHO | Diarrhoeal disease,” n.d.).

WHO recommends key environmental prevention strategies, including access to safe drinking-water, use of improved sanitation facilities, and hand-washing with soap. Treatment measures include rehydration with oral rehydration salts (ORS), which is a mixture of clean water, salt, and sugar. ORS combats the dehydration effects of diarrhea, and can replace the water and electrolytes lost during diarrheal episodes. Zinc supplements can also reduce the severity and duration of diarrhea cases(“WHO | Diarrhoeal disease,” n.d.). WHO and the United Nations Children’s Fund (UNICEF) jointly recommended zinc and ORS in combination to treat acute diarrhea in children in 2004, and such a policy was adopted by the Government of Uganda’s Ministry of Health in 2007. The United States Agency for International Development (USAID) funded the AFFORD Health Marketing Initiative to launch and distribute Zinkid zinc tablets, Restors ORS, and Aquasafe water purification tablets, across the country in 2007(Fischer, Karlan, McConnell, & Raffler, 2014).

The use of field water testing and mapping is generally underrepresented in field research, to the extent that no formal data reporting checklist a la CONSORT is available for either water test results or mapping, as Aimone et al reports in a systematic review(Aimone, Perumal, & Cole, 2013). Mapping, or more formally the use of Geographic Information Systems (GIS), has been used in the past in outbreak investigations, to map the prevalence of diseases such as malaria and anemia(Aimone et al., 2013). However, mapping in general is costly and requires a number of technical skills, things that many field researchers lack. Indeed, this project consulted experts outside of Duke University for the water testing and mapping techniques, from the University of North Carolina’s Spatial Health Research Group as well as the Georgia Institute of Technology, as resources were not available within the university.

As Bain et al. and Shields et al. demonstrate, the determinants of poor water quality remain poorly understood. The majority of studies of safe water concentrate on water at the source, and there is comparatively less information about the quality of water at the point-of-use or factors influencing that quality. Infrastructural indicators of safe water are predicated on a number of assumptions, for example, that household using piped water supplies consume completely clean water at the point-of-use, yet little evidence exists to justify many of these assumptions, and there may be assumptions that are yet to be discovered.

Generally speaking, the association between access to water, and the prevalence of both malaria and diarrhea, is poorly understood. The *Escherichia coli* bacteria is proven to be a causal factor of diarrhea, though some evidence suggests that beyond a certain concentration threshold, the bacteria is no longer clinically relevant(Gruber, Ercumen, & Colford, 2014). Thus, the association between access to water, and water quality at point-of-use, needs research.

The connections among water and water factors, and malaria specifically, remain poorly understood. Water is understood to affect malaria indirectly, in the sense that standing pools of water are ideal breeding spots for the mosquito vectors that carry the malaria parasite, but otherwise how water availability, access and sanitation affect the prevalence of malaria is not well understood(Keiser et al., 2005).

The specific water and sanitation conditions relative to malaria and diarrhea for this parish are unknown. This study is part of a community-based research initiative, so much of this study is devoted to exploring how water, sanitation, diarrhea and malaria are understood locally. The local knowledge of diarrhea and malaria, possible causes, symptoms and treatments of both, have not been previously described to our knowledge, which makes the self-reporting of malaria and diarrhea incidence difficult to verify and measure accurately.

Mapping and water testing provide useful supplementary data, yet the relative underrepresentation of these techniques in the literature make the adoption of mapping and water testing difficult. Thus, the project also aims to highlight qualitatively some of the benefits and challenges of mapping and water testing in the field.

This is the first study to systematically assess the state of water access in the parish. Previously, the number and type of water resources, unimproved vs. improved, by village, were not available as documented in the literature to our knowledge. The safety of each water source, bacteriologically, was also unknown. No geographic studies have been previously done in the parish, and sanitary conditions within the parish were poorly understood.

Through concentrating on this parish, this project hopes to describe water quality at the point-of-use level more generally, and uncover some of the factors correlated with that water quality.

V. General Purpose and Study Aims

- To describe the state of water access and quality in a rural parish in Central Region 2 of Uganda, by documenting the water resources that are available, access to water, water storage and treatment behaviors and bacterial levels in sources.
- To understand the burden and knowledge of malaria and diarrhea in the parish, and the water and sanitation factors that could be associated with this burden
- To investigate field water testing and mapping as a research and data collection strategy, and challenges in using these techniques

The ultimate purpose of this project, and of the community partnership as a whole, is to improve the health of residents in the parish by providing data to local health professionals and other stakeholders which they can then act on. Data on the state of water in the parish, as well as water transport, storage and treatment behaviors, is lacking, so the primary goal of this project is to describe water quality and access as it currently exists in the parish. As malaria and diarrhea are both influenced, in part, by water, and as both diseases are among the top causes of morbidity and mortality in Uganda(Wanzira et al., 2014) ("WHO | The top 10 causes of death," n.d.), this project continues the partnership malaria surveillance effort and implements a diarrhea surveillance effort in concert with the water aspect. Mapping and water testing are integral parts of this project, yet as both techniques are underrepresented in epidemiological studies in the literature, this project will also aim to investigate the use and challenges of such techniques in the field.

VI. Specific Objectives and Hypotheses

In terms of water investigation, specific objectives include:
1) to describe the current state of water quality in the parish, including the types of sources and contamination levels in those water sources,
2) to identify distance and frequency data for obtaining water on a village-by-village basis, and
3) to elucidate possible factors in household water contamination (including transport, treatment, and storage of water).

It was hypothesized that water from “improved” water sources should be both safer than that from unprotected water sources, and conformant to WHO standards, both at the source and at the point-of-use. It was hoped and additionally hypothesized that, should respondents indicate boiling or another point-of-use treatment for their water, water at the point-of-use level should be safer than water at the source level.

In terms of malaria and diarrhea work, specific objectives include: 1) to assess and quantify the number of households using insecticide-treated bed nets, and the association between ITN usage and malaria 2) to understand the state of sanitation in the parish at the time of research (including latrine usage, animal ownership, soap usage, hand-washing behaviors and household conditions), 3) to identify potential water and sanitation factors influencing malaria and diarrhea outcomes, 4) to describe and quantify the treatment-seeking behaviors of residents with household diarrhea cases, and 5) to describe the local understanding of diarrhea. It was hypothesized that, as a whole, the burden of malaria should be improved over the course of the year. It was further hypothesized that household with elevated levels of bacteria in water, and poor sanitary conditions (inadequate latrines, lack of latrine hand-washing facilities etc.) could have elevated malaria and diarrhea prevalence.

In terms of GPS and general methods for data collection, specific objectives include: 1) to assess challenges in the field usage of GPS tools as a research instrument, and 2) to assess the challenges of field water testing as a research instrument.

VI. Methods

This project surveyed 126 households, nine from each of the 14 villages using the survey instrument described below. Water samples were taken from each of the households surveyed, as well as 16 water sources (11 open springs, 4 boreholes, 1 piped water tap). Every location where water samples were taken was also mapped, both water sources and all households surveyed.

The parish is a rural parish, located about a few miles west of the main market town of the district, which on the whole is rural. Researchers stayed in the adjacent market town but traveled by motorcycle taxi to the parish and among villages nearly daily.

The Village Health Team (VHT) program is a program undertaken by the Uganda Ministry of Health with the help of the United States Agency for International Development (USAID) that assigns 2-3 volunteer Village Health Team Volunteers to each village, dependent on the size of the village. These VHTs were the primary points of contact within each village, and served as guides throughout the survey process for each village. The VHTs for each village maintained census booklets enumerating each household, and this served as the sampling frame to choose individual households (sampling units) randomly.

A large community introductory meeting with all of the VHTs in the parish was held at the beginning of the study period to explain the goals, aims and logistics of this and other projects performed in the parish. Regular meetings were held throughout the study period as well. The dates, times and procedures for visiting each village were decided at these meetings and via phone calls.

Each village was visited once, with all nine households per village surveyed on the same visit. In practice, at least two villages were visited per week, and parish visits performed nearly daily for other tasks. The visits usually began in the late morning and ended in the early afternoon period. At least one VHT accompanied the research team, myself and one translator, on each village visit, directing us to the selected households. Adult household members who are present at the time of survey served as respondents for that household.

The survey data collected for each visit was entered into the computer that evening, and water testing was performed for the water samples collected that day the evening as well.

A) Survey

The survey instrument was created and modified in the months leading up to data collection. Survey questions were taken and modified from existing World Health Organization surveys, Uganda Ministry of Health surveys, and surveys used by Dr. Marc Jeuland of Duke University and his research teams. The survey is split into six sections: demographics (4 questions), household conditions (5 questions), water access and sanitation practices (20 questions), knowledge of diarrhea (3 questions), prevalence of diarrhea (11 questions), and prevalence of malaria (10 questions). The question types include a mix of continuous questions (i.e. age) and discrete questions (with discrete answer choices).

For assessing malaria and diarrhea incidence, self-reported measures remain the only feasible option. However, as Johns et al. found, self-reported measures in general tend to underreport(Johns & Miraglia, 2015).

Per IRB regulations, written informed consent was performed prior to surveying at each household. A script in English was provided to our translator, and he facilitated the informed consent process with each respondent. Respondents signed on individual typed informed consent papers.

In each village (14 villages total), nine (9) households were chosen at random to be surveyed, for a total of 126 households. The village health team (VHT) volunteers maintained census booklets of each household within a particular village. Each household listed in a particular census booklet was numbered, and then a random number generator was used to select nine households, and an additional nine backup households, to be surveyed.

A particular village was surveyed each day, and each survey was administered at the respondent's household in the late morning or early afternoon times. Survey dates and times were arranged with a village's VHT volunteer beforehand, and the VHT facilitated our village visit and led our team to each household.

The survey is written in English. At the beginning of the survey period, the survey was discussed in full with translators. Protocols on data protection, safety, informed consent and respondent privacy rights were discussed with translators, and a written translator agreement was signed. For each household visit translator translated the survey on-the-spot. The survey used is provided in Appendix B. The length of time spent on a survey varied from 5 to 20 minutes, depending on the complexity of survey responses. In a household visit sequence, the survey was the first item performed, followed by water sample collection and GPS location-tracking.

Prior to each survey date, survey fields were written in a paper notebook to facilitate data collection. Survey answers were initially recorded by hand on paper notebooks, and later transferred to spreadsheets on a laptop computer.

B) Water Testing

Two measures of water testing were used in this project: *E. coli/*coliform Petrifilm plates (3M, Maplewood, MN) and nitrate testing using test strips (Nasco, Fort Atkinson, WI). Both water tests were identified and recommended by Dr. Marc Jeuland of Duke's Global Health Institute. There is a strong association between *Escherichia coli* counts and diarrhea incidence; *E. coli* is a WHO-preferred indicator for measuring water safety. Coliforms are generally accepted as a surrogate, however, coliforms could also have environmental origins. The count of total number of bacteria is used for data analysis purposes, especially as both types of bacteria are valid for process indicator purposes such as assessing the efficacy of water treatment methods(Gruber, Arnold, Reygadas, Hubbard, & Colford, 2014).

The Petrifilm plates provide a quantitative count of the number of *E. coli*/coliform colonies per 1ml of water. The EC 3MTM PetrifilmTM growth medium contained lactose and an indicator dye, such that total coliform bacteria appear as red colonies with the presence of gas bubbles. In addition, 5-bromo-4-chloro-3-indolyl-betaD-glucuronide (BCIG) is present in the Petrifilm medium for the detection of the enzyme beta-glucuronidase which cleaves BCIG giving a blue precipitate to beta-glucuronidase positive bacteria such as E. coli. Suspected bacterial colonies produce no associated air bubbles. All three measures were collected for each test, and a "total" measure was calculated based on these three indicators. Additionally, test results that meet or exceed 550 colonies were coded as "too many to count" and inputted as 550 in the spreadsheet. For training purposes, 3M's interpretation guides and videos available online were consulted.

3M Petrifilm plates, compared to the gold-standard of membrane filtration in enumerating bacteria, have been shown to have weak sensitivity (39%) but high specificity (90%)(Hörman & Hänninen, 2006). As Pearson et al. states, "this is consistent with other studies that found Petrifilms to be an insensitive measure of CFU to assure safe drinking water, but sensitive enough for screening and monitoring of recreational water"(Pearson, 2008). Thus, 3M Petrifilm plates cannot be used to confirm the safety of a water source, but can be used to detect unsafe water sources; if anything, the test undercounts bacterial levels.

The nitrate/nitrite strips result in a color change when incubated for one minute in a positive water sample. This color change was compared to an interpretation guide that the supplier provided.

Water collection procedure

Water samples were collected from each household surveyed, as well as a number of parish water sources, for a total of 144 samples. For each household visit, which usually took place during the late morning or early afternoon, the research team consisted of a translator, a Village Health Team (VHT) volunteer, and myself. At each household, respondents were asked to provide a cup of their household drinking water during a household visit, and asked which water sources respondents primarily used. During each village visit, all the water sources in the village as provided by VHTs were also visited, and water samples taken from each source. Samples were collected in transparent plastic cups with lids, and each cup was bagged in a zipper storage bag to prevent spillage. As nine households per village were surveyed, and as each village contained up to 3 water sources, 9 to 12 water samples were collected each day.

After each surveying day, the water samples from the village surveyed were taken to the researcher's place of residence and tested and/or incubated on a table in a room. For the nitrate/nitrite strips, each strip was submerged in a water sample for approximately 60 seconds. Results/color changes were visible and recorded immediately afterwards. For the Petrifilm plates, per 3M's protocol, 1ml of each water sample was transferred to each plate via demarcated disposable plastic pipettes. The plate was then pressed per instructions, then incubated at room temperature for 48 hours, on a table in an enclosed room. The number of confirmed *E. coli*, confirmed coliform, and suspected colonies were then counted with the help of clicker counting application on my phone. Pictures were taken of abnormally good or bad samples for representative purposes.

C) Mapping

Mapping was performed with a Garmin Oregon 550T handheld GPS unit. Accuracy levels with this unit range from a 4 meter radius in low-rise settings, up to 10 meters in forested environments(Bettinger & Fei, 2010). Beekhuizen et al. found that among three handheld GPS devices of the same, semi-recreational standard, the Garmin Oregon was the most accurate, especially in low-rise settings(Beekhuizen, Kromhout, Huss, & Vermeulen, 2013).

To facilitate the mapping process, an OpenStreetMap base map for the greater East Africa region was pre-loaded onto the unit. This base map contains basic roads and water features for reference purposes.

For data collection and analysis methodology, Mark Thomas of Duke University's Perkins Library Data and GIS Visualization Laboratory, and a researcher from the University of North Carolina's Spatial Health Research Center, were consulted.

This GPS unit was powered by AA batteries. Multiple sets of rechargeable batteries were stored and used.

Individual locations were recorded using the “waypoint” function on the GPS unit. Additionally, all of my travels were recorded using the “track” function on the unit.

All households surveyed, as well as all water sources in the parish, were location-recorded. The GPS mapping function was performed last in each household visit. The unit recorded latitude, longitude and elevation data. For water sources, descriptive statistics were also manually inputted as relevant.

Mapping data was backed up after each surveying day to my encrypted computer, using the Garmin Basecamp Application, the DNRGPS application and ArcGIS 10.1 by ESRI.

For the data analysis sections, missing roadways and paths were filled in manually using road-editing functions in ArcGIS based on satellite imagery. Direct and walking distances were then calculated with the distance tool in ArcGIS.

D) Data Safety

Informed, written consent was implemented at each household surveyed. For data collection and input, each respondent was assigned a unique code that spans their survey responses, water testing results and mapping data.

A digital master code sheet was kept and secured separately from the data, and all data linked to a respondent was labeled only with the aforementioned respondent code. Initially, written physical master code sheets were used, but all physical master code sheets were destroyed after transfer to digital formats. All digital data is encrypted with BitLocker.

For reporting purposes, only broad trends and statistics are reported. This report and appendices contains only broad-based results, and mapping data has been stripped of individual respondent locations.

Prior to the study start date, Institutional Review Board (IRB) approval was obtained from both Duke University and from the local District Health Office in Uganda.

E) Ethical Considerations

General Framework Ethical Discussion

As in all GH work, our relationship with the parish is complex, encompassing many considerations including differential power dynamics, the ethics of GH short term field work, the ethics of surveying and results reporting, and the balance between benefits to ourselves and our primary stakeholders: namely the individuals making up our community participants. We try to keep the ideals of community based participatory service-research central to all these considerations. The following is a brief discussion of the issues and our handling of them.

This study, and Duke's activities in the parish, take place within the overall framework of the community partnership. Partners within the district include district officials, officials from the district hospital, local non-governmental organizations, village health team volunteers, and parish school headmasters, teachers, and parents. During the study period, meetings are held with all of these partners, as well as meetings with parish mothers whose infant children participate in anthropometric measurement programs and any other adult community members recruited to participate in other studies, such as water and sanitation or cardiovascular disease monitoring. Additionally, the community gathers together during our annual health fairs for the community, during which health education and dissemination occurs, some years explicitly on the Duke Team's research findings.

However, there is no community-wide meeting that includes all 14 villages together to explain our overall research goals, directions and year to year findings. We depend on district officials, school head masters and teachers, and village health team volunteers as well as the general recruitment and consent meetings we hold with potential participants. However, as we are foreigners, and as our primary intermediaries are also in positions of power, power dynamics are prevalent and can cloud ethical considerations and community relations.

In order to try and mitigate this, in some years, teams have made simple laminated brochures to hand out to participants that distill in picture and simple narrative text main findings and recommendations of the past year's work. One year we discussed making a one-page calendar that would both distill information and be independently useful for residents. However, none of these methods has proved ideal and there is the possibility of disconnect between official administrative intermediaries, educational materials, and local residents themselves. For example, some residents have kept the research findings/recommendation deliverables and others have not. Typically, if we do see evidence of the deliverables over time, it is in official buildings like clinics or schools, vs. in residents' homes. Some residents seem aware of the goals of the work, but many are not.

Likewise, we have tried to present health information back to residents and health workers in a timely manner, and any bio-health data is owned and kept by local health authorities. We try and encourage research participants and community members to engage with local clinics and health workers and have tried to facilitate connections between community and accessible health systems. We continue working on best ways to deliver benefit back to primary stakeholders (the research participants themselves and their neighbors). This coming year, we have partnered with local health staff to deliver personalized information sessions to each research participant, or at least those found to be in lower health category groups. By integrating the research testing sessions with health consultations and feedback, we hope to provide more direct benefit and service give-back. It will remain to be seen if the additional time it takes to offer individualized health consultations is seen by residents as a good-practical use of their time. Regardless, it is of primary importance to the Duke team, that the balance between perceived and direct benefit to community and benefit to student learning is as equitable and ethically reflective as possible.

Specific Water-Project Ethical Considerations

Households were chosen at random to participate in this study. For each household surveyed, water tests were also performed. Due to logistical constraints, it is not possible to water test every single household in the village, yet it is possible that households who have significant water contamination, who could benefit from water testing and knowing their results, could be excluded from the study.

For households that were surveyed, it is logistically difficult to give water testing results directly to affected households. In the interim. at the point of survey, a brief deliverable of water treatment and sanitation tips is provided to households. The parish does not have a formal address system, so that GPS coordinates which are viewable only with appropriate technology effectively became the de facto address system. As a result, at times, some residents complained about being over-surveyed, without seeing or experiencing any tangible results.

For abnormal results, efforts were made to convey those results to village health team volunteers, who presumably could and should pass them along to affected households. In the opposite direction, this researcher passed along local residents' complaints about their water or sanitation status to local officials. After data analysis, all data, presentations and written work is provided to local officials, including water quality and geographic data, in disaggregated form to provide privacy. Poster deliverables are also given to community schools and other community institutions, to be displayed publicly.

The ultimate goal is to provide the data necessary for local officials and non-governmental organizations to take action. However, unfortunately, at no point yet in this process was data directly given to households surveyed themselves. In this coming year, there is the possibility that personal household level data could be delivered back directly to residents. However, other considerations also need to be taken into account. For example, direct linkage between our water testing and health outcomes is yet to be established, so balancing what course of action residents should be told to take and how grave not doing so is, needs to be carefully considered. Likewise, it is important to consider the access residents have to making specific changes we may recommend, as well as making sure messaging via our work and local water officials is consistent. Moving forward, we are opting to try out an educational assessment on cleaning water storage containers, which seems to be main source of increased bacterial contamination. If the educational intervention is effective, this could be a scalable, sustainable, and accessible procedure for residents to take ownership of and implement.

VII. Results

A) Study Population Overview

The study parish is located in Central Region II of Uganda, west of Kampala. Geographically, the area is dominated by gently rolling hills. This specific parish is located near a swamp area and bordering a large freshwater lake.

As with the rest of Uganda, the parish is located at a relatively high location on the East African Plateau. GPS readings suggest an average altitude of around 3600 feet, or 1100 meters. Thus, while the area is located geographically close to the equator, the climate is moderated by the high altitude of the area, so temperatures remain around 80 degrees Fahrenheit throughout the year. There are two periods of wet weather and two periods of dry weather annually; the wet seasons run from April to May and October to November, while the dry seasons are January to February and July to August.

Administratively, the parish lies under a sub-county, which lies under a district. While districts lie directly under the national level, districts are sometimes grouped into regions. Some parts of Uganda are additionally part of traditional kingdoms, which formally do not hold any power but informally are culturally influential.

The parish contains fourteen villages. The parish as a whole is rural in nature, however, a major road passes through this parish, and there is some market activity along the four villages that straddle the road. The parish also borders the main market town of the district.

Around 20 schools are located throughout the parish, as well as a handful of churches and mosques. The parish has one top-level government health clinic, as well as a lower-level clinic, however the nearest hospital is in the district market town. A number of non-governmental organizations, such as private non-profit health facilities and the local chapter of the Red Cross, are headquartered in the neighboring market town, however no sizeable non-governmental organizations operate in the parish itself.

The main water treatment facility for the entire district, which contains approximately 1,550 square kilometers, is located in the parish. At the time of survey, three villages had access to piped water; in 2015, six villages had this access, all along main roads. Piped water is provided by a government-owned for-profit entity, the National Water and Sewerage Corporation, which operates all piped water systems across the country and maintains a local office in the district market town.

B) Goal 1: To describe the state of water in a rural parish in Central Region 2 of Uganda, the water resources that are available, access to water, water storage and treatment behaviors

Objective 1: To describe the current state of water in the parish, including the prevalence and safety of water sources

Water Prevalence and Use

For each of the 126 households surveyed, respondents were asked what their main sources of water were. For each specific water source provided, that water source was visited and its type confirmed.

There are 11 open springs and 4 boreholes in the parish, as well as a plethora of private and shared piped water taps, private rainwater containers and one piped water user. On the household level, the water sources used across the parish are open springs (64% of households), boreholes (26%), piped water (6%), rain water (4%) and bottled water (one household). Residents used the word “well” in the Luganda language to describe, and what was later visually confirmed as, open springs. Thus, 32% of the parish uses what WHO defines as “improved” sources of water, which is lower than the statistics for the African continent as a whole(Bain et al., 2014).

The one user of bottled water for drinking is a retired banker with a post-secondary degree. This individual purchases one 18L container of bottled water every month for 500 shillings, and does not additionally boil the water. Testing at point-of-use revealed no detectable bacterial colonies.

Of the 14 villages in the parish, 3 villages had access to piped water at the time of survey (summer 2014). All 3 villages are located on the road leading from the area water treatment facility to the main market town in the District. Since then, an additional 3 villages have received piped water, all located along the main tarmacked road of the parish. 4 villages are located on the shore of a large, freshwater lake.

The following table list types and prevalence of water sources on the household level for each type of village, as described above, as well as for the parish overall. The sample sizes refer to the number of villages (i.e. 3 villages with existing piped water access), and the percentages refer to the percent of households using that type of water in each village category. For example, 25% of households in villages with direct lake access (4 villages) use open springs.

Table 1.1.1: Water Sources by Village Types 1

	Villages with Existing Piped Water Access (n=3)	Villages with Expansion of Piped Water Access (n=3)	Villages with Direct Lake Access (n=4)	Overall Parish (n=14)
Open Spring	55.6%	75.9%	25%	64%
Piped Water	29.6%	0%	0%	6%
Borehole	7.4%	11.1%	75%	26%
Rain Water	7.4%	3.7%	0%	4%
Other	0%	9.3%	0%	0%

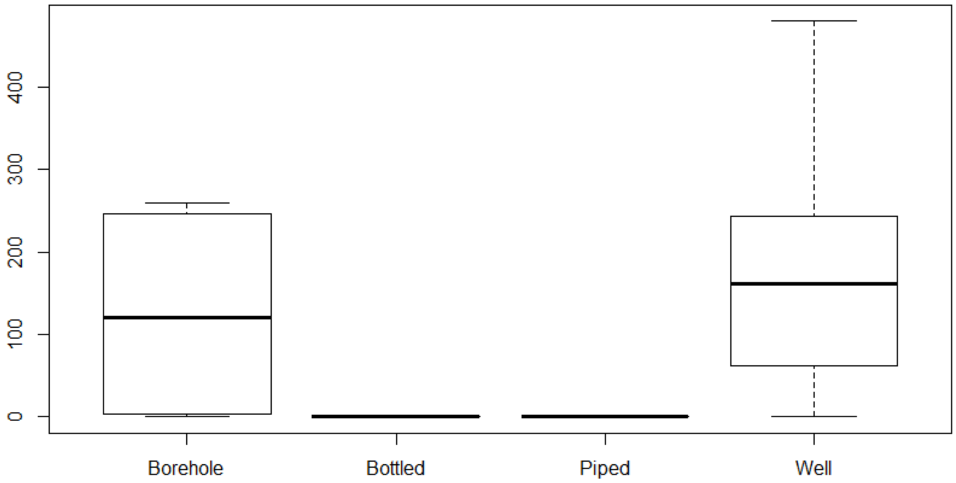
Piped Water Characteristics

Households who primarily use piped water either have a private piped water connection to the premises of the household (usually on the front lawn, but never inside houses themselves), live in multi-family housing that has a communal piped water connection, or access another household's piped water with a payment arrangement. For households with private water connections, the monthly water fee depends on the amount of water used, and can range from 10,000 to 20,000 shillings per month (1USD = 3338UGX, as of April 17, 2016). Households who access another household's piped water tap usually pay 300 to 400 shillings per jerry can (20L capacity). No respondents provided piped water installation fees, however, as a service project, the research team sponsored and funded the installation of piped water for a community school, and the total costs for that project was approximately 945,000 shillings.

Water Quality and Safety

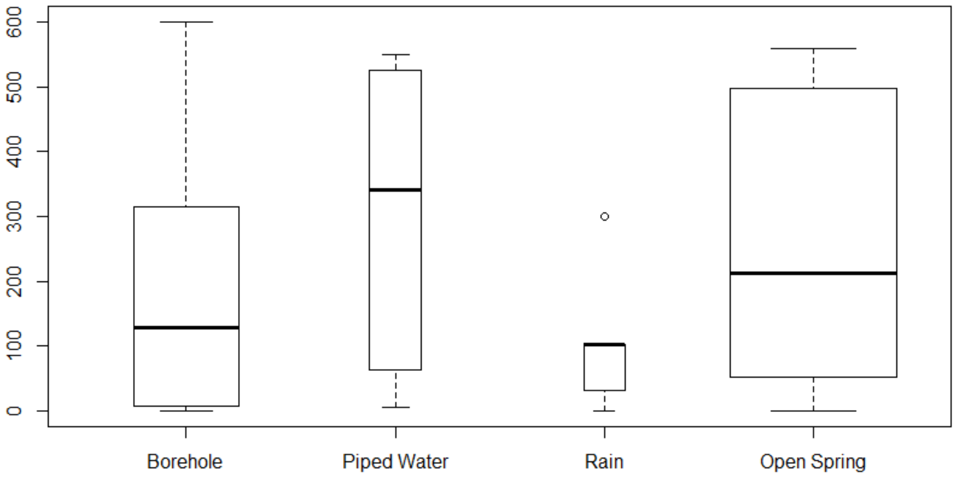
In Graph 1.1.2, bacterial test results are shown disaggregated by water source type, at the source. The Y axis represent the number of bacterial colonies present in one milliliter of water. Generally speaking, the water quality of improved sources (boreholes, bottled water, piped water) at the source is better than that of unimproved sources (wells = open springs); the improved sources all have median bacterial counts lower than, and spreads narrower than, the one unimproved source. However, the water quality of boreholes is still unacceptably high.

Graph 1.1.2: Water Quality (Total Bacterial Counts) By Source at the Source 2



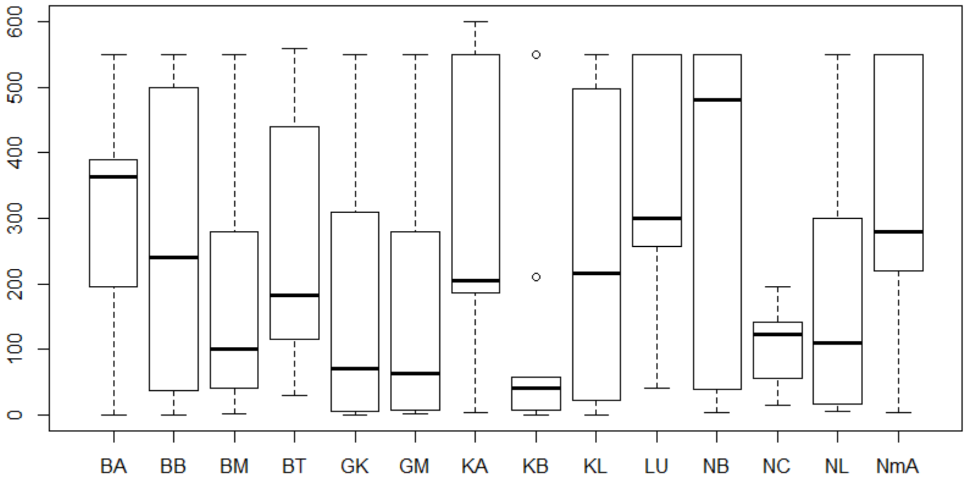
Graph 1.1.3 presents bacterial test results at the household point-of-use level, disaggregated by source type. At the household point-of-use level, the water quality of improved sources is as bad, or worse, than the quality of unimproved sources. While the median bacterial count for borehole is lower than that of open springs, the median for piped water exceeds that of open springs. As piped water is considered the "holy grail" of water sources, and as households with access to piped water are assumed to consume safe water, these results negate that assumption and show that piped water households consume water that is not only unsafe but also worse than that consumed by unimproved sources households.

Graph 1.1.3: Water Quality (Total Bacterial Counts) By Source at Point-of-Use 3



Two of the 14 villages have statistically-lower (by generalized linear regression model, p-values 0.05) bacterial loads at the point-of-use level (Graph 1.1.4). NC is the central village of the entire parish, where many schools, trading centers, and the main parish health center is located; both of the water sources are open springs. KB is a village located on the shore of the freshwater lake, with two boreholes.

Graph 1.1.4: Water Quality (Total Bacterial Counts) By Village at Point-of-use 4



Of the piped water recipients, most of them seem to be relatively wealthier. While direct wealth indicators were not assessed and while the housing quality data from the survey was not analyzed in conjunction with piped water use, anecdotally, it seems that the villages with access to piped water seemed to have more concrete and cement houses. With the presumed expansion of piped water across the parish, how socioeconomics influences piped water uptake is a research interest going forward. Across almost all water sources (the exception being bottled water), the water quality at the household is drastically different than the quality at the source. For open springs and boreholes, water samples were taken from both the household and the exact source that each respondent indicated they obtained their water from, and thus direct comparisons can be made. All other water types were compared indirectly with representative samples. Thus, Graph 1.1.5 directly compares bacterial levels between the water source and household point-of use, and applies only to open springs and boreholes, however the principle remains true for the other water sources. By Direct T-Test, this difference is trending towards significance, with a P value of 0.067.

Graph 1.1.5: Comparisons of Bacterial Levels between Water Source (Open Springs and Boreholes) and Household Point-of-Use 5

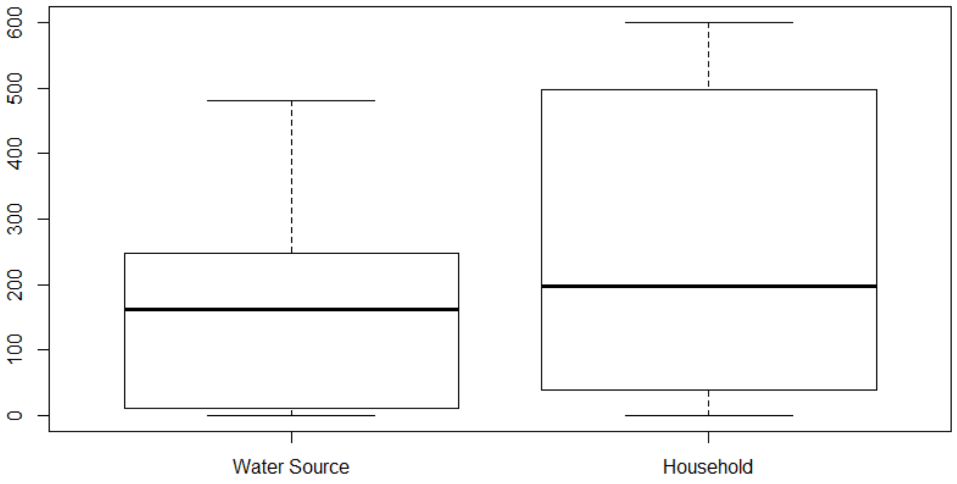


Table 1.1.6 compares selected indicators from the Solar Water Disinfection (SODIS) project undertaken by Duke students in 2010, with data collected in 2014. Both projects were cross-sectional, so while there may be some overlap in households surveyed, that likelihood is low. However, despite the caveats, the data suggests that water access and safety, as well as diarrhea statistics, seemed to have improved over time.

Table 1.1.6: Comparison of Selected Water Indicators Between 2010 and 2014 Data 6

	SODIS/2010 Result	**2014 Result**
Number of Households Surveyed	50	126
Gender of Respondents		
Female	82%	81%
Male	18%	19%
Reported Cases of Diarrhea in the Past 6 Months	18%	7%

Water Sources		
Open Spring	92%	64%
Borehole	6%	26%
Rain Water	2%	4%
Other (Piped, Bottled etc.)	0%	6%
Distances (Self-Reported for 2010), Majority Quartile	800-3200m	200-1400m
Boiling	72%	99.2%

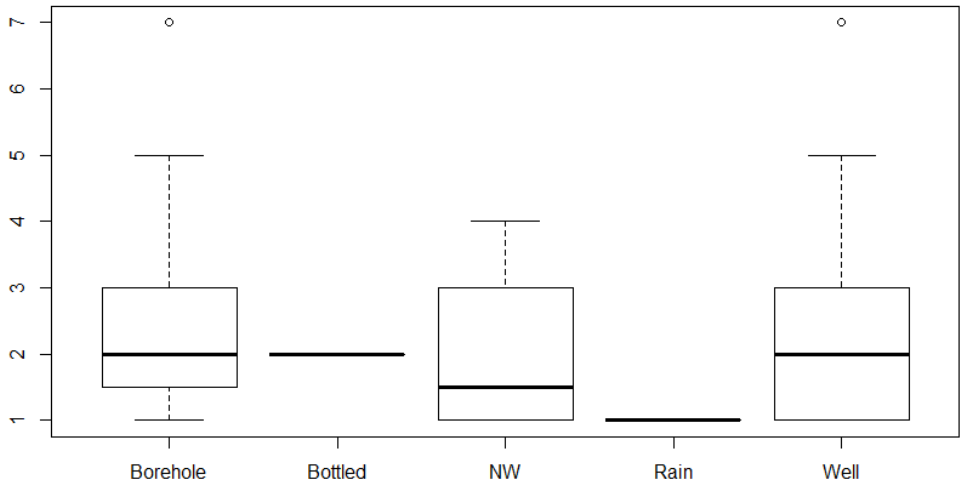
Objective 2: To identify distance and frequency data for obtaining water

The results below show data for the distance, time spend and frequency of obtaining water, disaggregated by water source.

In addition to the bacteriological standard for safe water, the World Health Organization additionally defines adequate access as an improved water source located 1km or less away from the household, and a supply of 20L of water per person per day. The vast majority of households who access shared water sources (non-private tap sources) use jerry cans to transport water; each jerry can has a capacity of 20L. However, 15 households (11.9%) exceed the 1km standard by direct distance, and 34 households (26.9%) exceed the 1km standard by road distance.

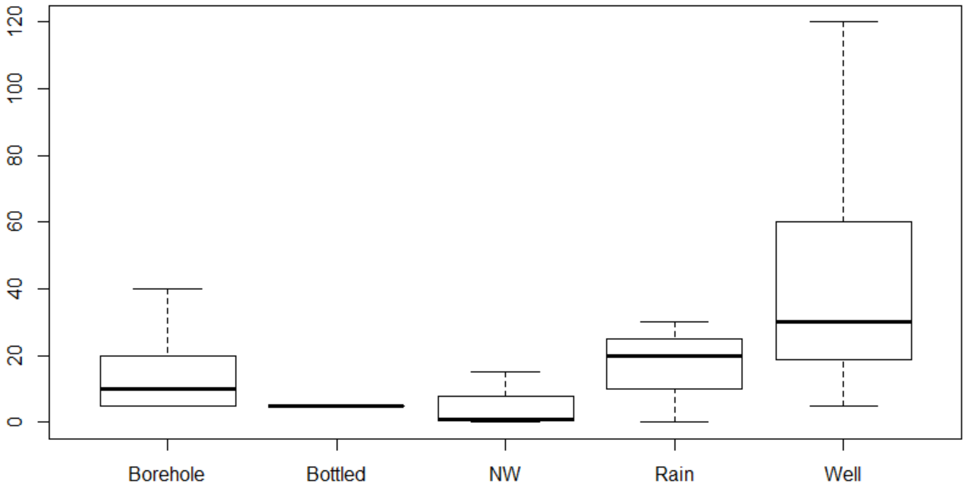
For boreholes, bottled water and open springs (denoted as wells), the median frequency for obtaining water is twice a week. For piped water sources (denoted as “NW” for National Water), the median is 1.5 times a week, while for rain water, the median is once a week. Graph 1.2.1 illustrates the frequency of obtaining water, as number of times per week (i.e. 7 on the Y axis is a daily frequency), disaggregated by water source. Very few households reported obtaining water on a daily basis; taken together with the distance statistics mentioned above, this suggests that very few households meet the WHO standard for adequate water access.

Graph 1.2.1: Frequency of Obtaining Water per Week, by Water Source 7



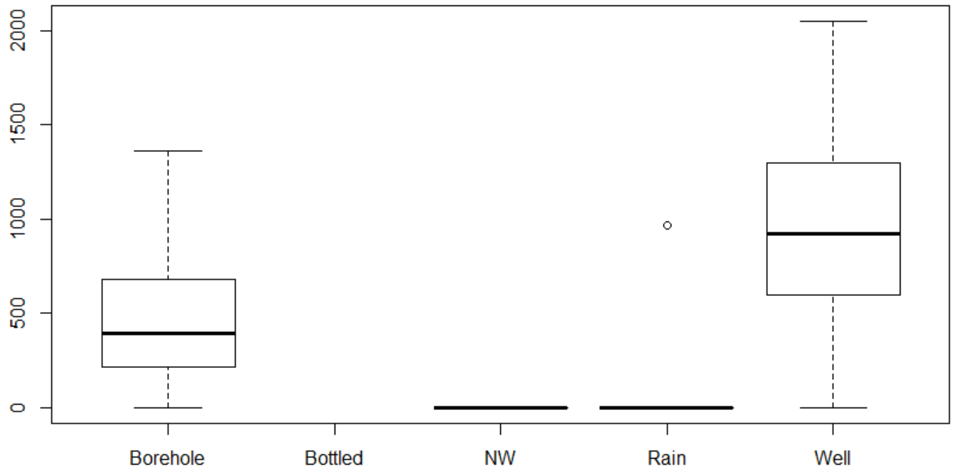
Graph 1.2.2 displays the self-reported times spent fetching water, in minutes per trip, disaggregated by source type. The time for open springs (denoted as "wells") is substantially higher than the time spent for all other water sources.

Graph 1.2.2: Time Spent Fetching Water by Water Source, in Minutes, Per Trip 8



Graph 1.2.3 displays road distances, as confirmed with GPS data and satellite imagery, disaggregated by source type. The self-reported time data above is reflected in the road distance data, where open springs (denoted as "wells") are located the farthest from recipient households, followed by boreholes.

Graph 1.2.3: Road Distance by Source, in Meters 9



There are two villages whose distances to their water sources are notably high. Both villages are located inland, and do not have water sources located within the village, instead using the water sources of neighboring villages. The first village, which has the largest average distances, is one of the smallest villages with only 26 households total (as maintained on the census records of the Village Health Team volunteers), however geographically the village is very spread out. The second village is notable as in the process of data collection, the village health team volunteers for this village petitioned me to ask district officials to install a water source in this village. The village almost two decades ago petitioned to have a water source installed, but no action was taken then (some administrative changes happened on a national level in the intervening years). This village is located along the main road, so there is a possibility of piped water expansion to this village.

Objective 3: To elucidate possible factors in household water contamination

The following results display summary statistics of some indicators which are possible factors in household water contamination, as well as a regression table which suggests which indicators may be significant.

Summary Statistics

Most residents walk to their water source to obtain water. 14 households (11.1%) either bike or hire cyclists, either in place of or as a supplement to walking, to obtain water.

125 out of 126 households reported boiling their water prior to consumption. The one household that did not report boiling water, used exclusively bottled water for drinking purposes.

The vast majority of residents (75%) reported storing their water in jerry cans. 12% reported storing water in pots. Jerry cans are 20L containers, frequently yellow-colored, that anecdotally look quite dirty from the outside. All households reported storage in containers that were "covered" and "elevated".

Regressions

Regression models (n=5) were created, with survey data, distances, bacterial counts and nitrate level factors as inputs, and bacteria, direct distances, road distances, diarrhea and malaria as outputs. In general, regressions reveal which indicators, or inputs, are statistically significant, and in what direct each unit of an indicator will influence the output.

The R programming language, as used in RStudio, was used to create and assess each regression model, using the lm (linear model) and glm (generalized linear model) commands. The data was initially entered into Excel. To prepare for regressions in R, answers for each discontinuous indicator were re-coded into 0s (no) and 1s (yes), and answer choices were separated out into separate columns; for example, the respondent gender question answers were separated into two columns (for male and female), and if a respondent was male, a 1 was entered in the male column and a 0 in the female column. Continuous indicators were left as-is. Inputs were assigned into categories (i.e. household demographics, knowledge of diarrhea, etc.) and exported as comma-separated value (csv) files to be imported into RStudio. A model was created for each of the five outputs, and each model was assessed separately.

The linear models can be theoretically visualized as X and Y axes graphs, with each indicator as the X axis and the output as a Y axis. While this can be done separately for each indicator (for example, a model of exclusively gender as input and total bacteria count as output), the inclusion of multiple indicators as inputs allows indicators, or factors, to be "controlled" for, which improves the validity of a significant indicator should one be present by accounting for possible confounders. The estimates thus are the amount of Y axis movement controlled by one-unit increase in the indicator for continuous variables; for discontinuous variables the estimate is the Y axis output difference between values of 0 (no) and 1 (yes)

The purpose of regressions in this project is to illuminate possible significant factors as leads for further research. This project was not designed with the correct statistical power to conclude conclusively any results, and the sample size of 126 households is too low, thus regression results are meant to be secondary.

The distance, bacterial count and nitrate level factors were assessed independently and objectively, while all other factors are derived from the self-reported survey.

Result 1.3.1: Logistic Regression Results for Total Bacterial Load, Direct Distances, Road Distances, Diarrhea and Malaria Total Bacterial Load (Output) – Demographics 10

	Estimate Bacteria	Estimate Direct Distance	Estimate Road Distance	Estimate Diarrhea	Estimate Malaria
Respondent Gender: Female	13.7684	-10.597	-41.9059	0.0017	0.1797^

Respondent Gender: Male	NA	NA	NA	NA	NA
Age	-0.7379	1.482	0.8951	-0.00048	0.00265
Last Year of Schooling	8.2972	7.145	2.6633	0.0074	0.0147
Occupation: Farmer	75.5133	-247.957	-121.7628	0.0735	0.0399
Occupation: Unemployed	56.4144	-423.695	-340.4836	-0.014	0.08264
Occupation: Shopkeeper	-89.0576	-299.388	-131.6298	-0.023	-0.1136
Occupation: Teacher7	194.6988	-150.049	-424.6004	-0.017	0.5478^
Occupation: Fisherman	-175.9557	-785.834^	-881.3797	-0.031	0.0145
Occupation: Mechanic	-197.9060	-779.505^	-894.8362	-0.025	0.089
Occupation: Retired	-45.4681	-406.891	-51.0363	-0.035	-0.0077
Occupation: Food	-138.7051	-574.396	-612.1577	0.026	-0.078
Occupation: Merchant	-151.8888	-520.783	-584.6581	0.019	0.409
Demographics: Independent House	-31.6855	-435.42	-751.781	-1.2968	-0.128
Demographics: Tenement	12.8779	-725.14	-1141.722	-1.251	0.136
Demographics: Independent Flat/Apartment	NA	NA	NA	NA	NA
Demographics: Hut	NA	NA	NA	NA	NA
Demographics Uniport	NA	NA	NA	NA	NA
Demographics: How Many Rooms in House	19.6	-56.47*	-75.112^	0.022	0.054*
Demographics: How Many Children in House	-0.5506	-14.19	-14.148	-0.0036	0.006
Demographics: Construction Material of Roof and Walls is Thatch/Straw	11.2442	167	270.515	0.056	-0.288
Demographics: Construction Material of Roof and Walls is Mud	52.053	-239.8	-333.604	-0.4	-0.135

Demographics: Construction Material of Roof and Walls is Wood/Plants	114.5794	-82.06	-54.199	0.0536	-0.428
Demographics: Construction Material of Roof and Walls is Iron Sheets	26.9318	318.86	633.596^	0.0418	-0.468
Demographics: Construction Material of Roof and Walls is Asbestos	NA	NA	NA	NA	NA
Demographics: Construction Material of Roof and Walls is Tiles	-203.5714	-182.39	-345.995	-0.203	0.105
Demographics: Construction Material of Roof and Walls is Tin	NA	NA	NA	NA	NA
Demographics: Construction Material of Roof and Walls is Cement	-74.5798	125.17	590.432	0.0213	-1.041
Demographics: Construction Material of Roof or Walls is Iron Sheets + Concrete	175.911	-404.77	-810.76	-0.11	0.6756*
Demographics: Construction Material of Roof and Walls is Other	-97.9668	-981.64	-1133.452^	-0.108	-0.376
Demographics: Construction Material of Floor is Earth	25.0765	156.27	264.471	-0.0482	-0.103
Demographics: Construction Material of Floor is Cow dung	-11.6828	-55.38	62.693	-0.133	0.132
Demographics: Construction Material of Floor is Cement	-157.2641	139.41	207.07	-0.5525*	0.034
Demographics: Construction Material of Floor is Mosaic/Tiles	-210.8897	374.37	300.812	-0.6262^	-0.1298
Demographics: Construction Material	62.4397	-84.59	-61.048	-0.4354*	0.147

of Floor is Bricks					
Demographics: Construction Material of Floor is Stone	89.0650	-252.58	-279.47	-0.0102	-0.239
Demographics: Construction Material of Floor is Wood	-40.9881	-172.42	-161.079	-0176	0.184
Demographics: Construction Material of Floor is Cement + Bricks	23.9838	107.59	-4.032	0.4277*	-0.196
R-Squared	0.150	0.202	0.165	0.170	0.175
Number of Observations	122	122	122	122	122

Result 1.3.2: Logistic Regression Results for Total Bacterial Load, Direct Distances, Road Distances, Diarrhea and Malaria Total Bacterial Load (Output) – Water Inputs 11

	Estimate Bacteria	Estimate Direct Distance	Estimate Road Distance	Estimate Diarrhea	Estimate Malaria
Direct Distance to Water Source	-0.07411	NA	NA	1.075e-03	4.803e-05
Road Distance to Water Source	0.12899	NA	NA	0.0852^	0.08757*
Water: How often water is obtained per week on average	-24.398*	24.403	-24.31058	-25.129*	-24.366*
Water: How long does it take to get water	-0.02829	7.838	-0.08017	-3.63e-04	-1.664e-03
Water: Transportation is Walking	48.94774	-116.151	53.68957	-6.823e-02	3.558e-01
Water: Transportation is Biking	-30.18838	37.982	-33.2455	1.007e-01	4.707e-01
Water: Yes Payment	-72.53038	89.016	-75.41101	6.901e-02	-8.448e-02
Water: Treatment is Boil	-751.2	1937.399	2543.34	0.61	0.359

Water: No Treatment	NA	NA	NA	NA	NA
Water: Storage Container is Pot	288.50	1153.5*	1171.74^	0.259	0.196
Water: Storage Container is Jerry Can	299.55	1102.1*	1159.12^	0.083	0.047
Water: Storage Container is Saucepan	15.40	1044.91^	962.78	0.0567	1.437**
Water: Storage Container is Drums	NA	NA	NA	NA	NA
Water: Storage Container is Jug/Kettle	246.47	806.734*	689.33	0.0455	-0.8009
Water: Storage Container is Bottle/Flask	495.24*	902.99^	846.05	0.0118	0.102
Water: Storage Container is Bucket	-27.32	585.723	318.85	0.1224	0.0099
Water: Storage Container is Covered	NA	NA	NA	NA	NA
Water: Storage Container is Elevated	-288.05	263.752	367.57	0.103	-0.0383
Water: How Often Storage Container is Cleaned	-18.38	22.713	29.51	0.0075	0.0015
Water: Covered Pit Latrine Private	-268.24	11.391	83.76	0.0696	0.059
Water: Covered Pit Latrine Shared	-221.79	57.196	32.04	0.1555	0.265
Water: Uncovered Pit Latrine	-245.91	25.636	89.40	0.0378	0.075
Water: No Hand Washing Facility at Latrine	301.09	189.336	133.29	0.0378	-0.925**
Water: Hand Washing Facility at Latrine	277.61	184.135	160.89	-0.0038	-0.970**
Water: Use of Soap	-52.75	48.001	-39.12	0.151	0.407**
R-Squared	0.359	0.370	0.350	0.346	0.363
Number of Observations	125	125	125	125	125

Result 1.3.3: Logistic Regression Results for Total Bacterial Load, Direct Distances, Road Distances, Diarrhea and Malaria Total Bacterial Load (Output) – Sanitation 12

	Estimate Bacteria	Estimate Direct Distance	Estimate Road Distance	Estimate Diarrhea	Estimate Malaria
Domestic Animals: No	359.43*	-56.061	-41.06	0.0438	-0.491^
Domestic Animals: Yes	442.10*	11.793	61.33	0.0181	-0.518^
Domestic Animals: No Answer	488.91^	536.408	781.78	0.983**	-1.061*
Public Health Messages Received: Hand Washing	126.68	-237.351	-180.59	0.0323	-0.109
Public Health Messages Received: Water Storage and Treatment	35.24	458.17^	514.08	-0.09496	0.478*
Public Health Messages Received: Personal Hygiene	37.86	392.3^	495.52^	-0.0302	0.515**
Public Health Messages Received: Sanitation/Excreta Management	-37.17	277.366	190.48	-0.0317	0.482**
Public Health Messages Received: Water Storage + Hygiene	-222.82	-695.442*	-757.39^	-0.0437	-0.447^
Public Health Messages Behaviors Changed: Use Piped Water	180.40	-105.371	-235.49	0.0483	0.057
Public Health Messages Behaviors Changed: Stop Open Defecation	75.26	100.241	30.11	0.1421	0.232
Public Health Messages Behaviors Changed: Use Individual Household Latrine	-59.96	-6.681	-133.94	0.156*	-0.117
Public Health Messages Behaviors Changed: Wash Hands with Soap	-59.94	-240.762	-200.63	0.0708	-0.442*

Public Health Messages Behaviors Changed: Safely Store Water	25.46	16.209	104.98	-0.0901	0.0226
Public Health Messages Behaviors Changed: Treat Water	-81.45	-274.590	-197.67	0.0225	-0.557**
Public Health Messages Behaviors Changed: Wash hands with soap + store drinking water safely + treat water	183.66	218.437	13.65	0.0403	0.483*
R-Squared	0.359	0.370	0.350	0.346	0.363
Number of Observations	125	125	125	125	125

Result 1.3.4: Logistic Regression Results for Total Bacterial Load, Direct Distances, Road Distances, Diarrhea and Malaria Total Bacterial Load (Output) – Knowledge of Diarrhea 13

	Estimate Bacteria	Estimate Direct Distance	Estimate Road Distance	Estimate Diarrhea	Estimate Malaria
Knowledge Symptoms of Diarrhea: Loose/Watery Stool	-62.817	70.293	114.625	-0.0028	0.139
Knowledge Symptoms of Diarrhea: Bloody Stool	-112.502	8.050	81.448	-0.0623	-0.108
Knowledge Symptoms of Diarrhea: Abdominal Pain	-33.804	61.395	35.007	-0.0686	0.061
Knowledge Symptoms of Diarrhea: Soft Part Sunken	297.377	-308.608	-278.159	-0.0024	-0.085
Knowledge Symptoms of Diarrhea: Fever	35.590	16.475	117.682	0.229*	0.236^
Knowledge Symptoms of Diarrhea: Vomiting	-53.943	-26.833	-16.452	0.0104	-0.127
Knowledge Symptoms of Diarrhea: Weakness	-118.719	-271.962	-481.294	-0.299^	0.0086
Knowledge Symptoms of Diarrhea: Dehydration	-164.5	-53.215	-138.461	-0.183	0.133

Knowledge Symptoms of Diarrhea: Loss of Sense	-271.5^	194.948	267.242	0.293^	-0.139
Knowledge Symptoms of Diarrhea: Headache	-25.929	-46.051	-69.432	0.0437	0.237
Knowledge Symptoms of Diarrhea: Constipation	23.422	-58.422	-70.227	0.0499	-0.200
Knowledge Symptoms of Diarrhea: Other	472.643^	-72.31	-209.228	0.118	-0.339
Knowledge Symptoms of Diarrhea: Don’t Know	151.953	76.676	197.989	-0.0572	-0.003
Knowledge Symptoms of Diarrhea: Abdominal Pain + Dehydration	128.919	2.902	29.609	0.0263	-0.041
Knowledge Causes of Diarrhea: Eating Stale Foods	-94.292	80.035	116.736	-0.0491	0.072
Knowledge Causes of Diarrhea: Eating Non-Homemade Foods	118.419	-91.872	-219.989	-0.1217	0.132
Knowledge Causes of Diarrhea: Eating Foods touched by Insects	-98.247	-17.933	-66.882	0.0570	0.0996
Knowledge Causes of Diarrhea: Unclean/Smelly Food	28.513	41.938	069.131	0.0525	-0.153
Knowledge Causes of Diarrhea: Drinking Bad Water	57.51	238.942	320.35	0.116	0.154
Knowledge Causes of Diarrhea: Drinking Water Not Fresh 11	164.862^	95.531	183.13	-0.106	0.663
Knowledge Causes of Diarrhea: Using unhygienic latrines or open defecation	-103.273	-428.453^	-492.936	0.0037	0.663**
Knowledge Causes of Diarrhea: Open Drains/Bad Drainage	-5.857	218.382	227.128	0.215	-0.571*
Knowledge Causes of Diarrhea: Not Washing Hands	225.009	-87.839	136.502	0.143	0.213

Knowledge Causes of Diarrhea: Bad Weather	NA	NA	NA	NA	NA
Knowledge Causes of Diarrhea: Exposure to Sun	-264.736	-151.721	-8.098	-0.334	-0.164
Knowledge Causes of Diarrhea: Changing Water Source	-26.961	291.055	394.595	-0.179	-0.096
Knowledge Causes of Diarrhea: Household Uncleanliness	-23.235	-109.682	-38.867	-0.076	0.083
Knowledge Causes of Diarrhea: Village Uncleanliness	56.964	57.154	209.408	0.085	0.024
Knowledge Causes of Diarrhea: Don't Know	-211.037^	152.845	605.842^	-0.0191	-0.037
Knowledge Treatment of Diarrhea: Use ORS	-49.282	-191.063	-390.52^	-0.0284	-0.175
Knowledge Treatment of Diarrhea: Take Certain Foods	-95.602	649.081	515.802	-0.0897	-0.650
Knowledge Treatment of Diarrhea: Avoid Certain Foods	NA	NA	NA	NA	NA
Knowledge Treatment of Diarrhea: Doctor/Hospital	-48.843	-172.702	-412.498	-0.02	-0.217
Knowledge Treatment of Diarrhea: Other	-57.951	99.188	-131.409	0.162	0.598
Knowledge Treatment of Diarrhea: ORS + Hospital	NA	NA	NA	NA	NA
R-Squared	0.327	0.320	0.314	0.333	0.331
Number of Observations	115	115	115	115	115

Result 1.3.5: Logistic Regression Results for Total Bacterial Load, Direct Distances, Road Distances, Diarrhea and Malaria Total Bacterial Load (Output) – Malaria Cases 14

	Estimate Bacteria	Estimate Direct Distance	Estimate Road Distance	Estimate Diarrhea	Estimate Malaria

Malaria: Use of a Bed Net	644.30	496.42^	644.30	0.992***	644.30
Malaria: Consistent Bed Net Use	328.07	244.17	328.07	0.109	328.07
Malaria: Knowledge, Largest Barrier to Preventing Malaria is Access to Anti-Malarial Drugs	-191.77	-64.90	-191.77	-0.07997	-197.77
Malaria: Knowledge, Largest Barrier to Preventing Malaria is Access to Nets	-185.82	-48.15	-185.46	-0.197*	-185.46
Malaria: Knowledge, Largest Barrier to Preventing Malaria is Knowledge About Malaria Transmission	-192.82	-88.57	-192.82	-0.043	-192.82
Malaria: Knowledge, Largest Barrier to Preventing Malaria is Don't Know	50.51	187.98	50.51	-0.149	50.51
Water Source: Piped Water	106.86	-356.43**	-458.78*	NA	NA
Water Source: Open Spring	71.43	323.02***	488.27***	NA	NA
R-Squared	0.327	0.320	0.314	0.333	0.331
Number of Observations	115	115	115	115	115

P values: ^0.10-0.05, *0.05-0.01, **0.01-0.001, ***<0.001

For total bacterial load, higher road distances are associated with higher bacterial loads, while obtaining water more frequently is correlated with lower bacterial loads.

For distances, water storage of any type is associated with greater direct distances. Piped water recipients have lower distances (both direct and road distances), while open spring recipients have higher distances.

For diarrhea prevalence, better housing materials (concrete/cement/iron sheets) are associated with lower diarrhea, as is obtaining water more frequently.

For malaria prevalence, obtaining water more frequently is associated with lower malaria.

B) Goal 2: To understand the burden of malaria and diarrhea in the parish, and the water and sanitation factors that could be associated with this burden

As self-reported in the survey, in the first half of 2014, the prevalence of diarrhea was 9 of 126 households (7.1%) and the prevalence of malaria was 20 of 126 households (16%).

Objective 1: to assess and quantify the number of households using insecticide-treated bed nets, and the association between ITN usage and malaria

The following results present relevant statistics for ITN usage and reported cases of malaria.

Usage of insecticide-treated nets (ITNs) in the parish is widespread and increasing. In 2013, 77.9% of all households, surveyed cross-sectionally, had at least one net, and of those, 86.2% were treated. In 2014, 96.8% of households, surveyed cross-sectionally, had at least one net, and of those, 97.5% were treated. The Government of Uganda began a national universal bed net distribution program in 2010, beginning with the Central Region. Most households reported obtaining their bed nets from the government, particularly in the Winter of 2013, so it appears that the Uganda National Malaria Control Program's efforts at universal bed net distribution is effective.

Only 20 households, out of 126 households surveyed, reported having malaria. An average of 1.2 people per household were infected. The sample size is too small to conclude statistically a correlation between ITN usage and malaria prevalence; however, 10% of the households with malaria cases did not have or use a malaria net, compared with 3.2% of the study population as a whole.

Four households surveyed either did not obtain any ITNs, or did not obtain enough during the government distribution. Two households reported not wanting ITNs.

Objective 2: To understand the state of sanitation in the parish at the time of research

The following results present relevant statistics for self-reported sanitation indicators assessed in the survey.

There is widespread latrine ownership and usage in the parish, however, most latrines are uncovered but roofed pit latrines. 52.3% of respondents reported using private and uncovered latrines, 19.8% covered latrines, 11.9% shared uncovered latrines, and 2.4% shared covered latrines. Thus only 19.8% of respondents use sanitation facilities that are "improved" as defined by WHO.

The majority of respondents (72%) indicated no ownership of household animals; 25% of respondents indicated ownership, and 3% did not answer. The majority of household animals are chickens, with pigs, cats, ducks and hens also represented.

Self-reported ownership and use of soap is near-ubiquitous, at 99.2%

Only 40% of respondents indicated having a handwashing facility, such as a jerry can or other container of water, at the latrine.

Housing conditions include concrete/cement houses (78%) and mud/earthen housing (22%), with an average of 3.4 rooms per house.

Objective 3: To identify potential water and sanitation factors influencing malaria and diarrhea outcomes

The following results and tables (2.3.1 to 2.3.10) compare summary and other relevant statistics for survey and water results among three cohorts: households with malaria cases, households with diarrhea cases, and for all households surveyed. For malaria, some discrepancies observed here, worthy of further research, are: the number and use of bed nets, housing construction type, use of unimproved vs. improved water sources, and types of water containers used. For diarrhea, those discrepancies include: education level, types of housing materials, use of unimproved vs. improved water sources, types of water containers used, water quality, and distances to water source. Many of these discrepancies are reflected in the regression results.

Table 2.3.1: Demographics 15

Gender of Respondents	*Malaria Households*	*Diarrhea Houses*	*All Households*
Female	18 (90%)	7 (77.8%)	102 (81%)
Male	2 (10%)	2 (22.2%)	24 (19%)
Average Age	42.1	40.3	42.8
Last Year of Schooling			
Range	No schooling to S5	No schooling to S4	No schooling to PostSec
Mode	P7	P6	P7
Occupation	Farmer 12 (60%)	Farmer 6 (66.7%)	Farmer 92 (73%)

Table 2.3.2: Household Conditions 16

Types of Houses			
Concrete/Cement	13 (65%)	6 (66.7%)	98 (78%)
Mud	7 (35%)	3 (33.3%)	28 (22%)
Number of Rooms/House			
Range	1-7	1-7	1-7
Average	3.6	3.78	3.4
Number of Children/Household			
Range	1-9	1-8	0-10
Average	3.9	3.9	3.57

Table 2.3.3: Access to Water 17

Sources of Water (Primary)	70%	88.9%	64%
Open Springs	30%	11.1%	26%
Boreholes	0%	0%	0%
Bottled Water	0%	0%	6%
Piped Water	0%	0%	4%

Rain Water			
Frequency of obtaining water (every x days)			
Range	1-7	1-3	1-60
Average	2.25	1.4	2.78
Time Spent Fetching Water (each time, in min.)			
Range	1-120	1-60	1-120
Average	26.5	30	30
Payment/Lack Thereof			
Percentage who Pay	15%	22.2%	15%
Average Amount of Payment	333 shillings	350 shillings	3013 shillings

Table 2.3.4: Household Water Treatment 18

Boiling Water	100%	100%	99.2%
Water Storage Container			
Pot	25%	33.3%	12%
Jerry Can	60%	66.7%	75%
Other	15%	0%	13%
Container Covered/Elevated	100%	100%	99.2%
Frequency of Cleaning storage container (every x days)			
Range	1-7	1-7	1-60
Average	2.45	2.78	2.9

Table 2.3.5: Sanitation Practices 19

Latrine/Bathroom Type			
Private Covered Pit Latrine	25%	33.3%	19.8%
Shared Covered Pit Latrine	5%	0%	16%
Uncovered Latrines	70%	66.7%	64.2%
Hand Washing at Latrine	40%	44.4%	40%
Domestic Animals in House	25%	11.1%	25%

Public Health Messages Received			
Personal Hygiene	60%	55.6%	49%
Water Storage/Treatment	20%	0%	18%
Other	20%	44.4%	33%
Sanitation Behaviors (multiple choices possible)			
Safely Handle/Store Water	55%	55%	57%
Wash Hands with Soap	45%	45%	54%
Treat Drinking Water	40%	40%	46%
Use Private Latrine	20%	20%	22%

Table 2.3.6: Knowledge of Diarrhea (Multiple Choices Possible) 20

Symptoms of Diarrhea			
Abdominal Pain	75%	66.7%	76%
Dehydration	45%	33.3%	32%
Fever	30%	66.7%	18%
Vomiting	20%	44.4%	18%
Loose/Watery Stool	30%	11.1%	13%
Causes of Diarrhea			
Household Uncleanliness	45%	11.1%	42%
Eating Stale Foods	35%	55.6%	38%
Stale Drinking Water	20%	33.3%	30%
Bad Drinking Water	25%	33.3%	11%
Treatment for Diarrhea			
Doctor/Hospital	85%	88.9%	89%
Oral Rehydration Salts	20%	44.4%	24%

Table 2.3.7: Prevalence of Diarrhea 21

Households with Diarrhea cases	*Diarrhea Households (n=9)*
Within last 3 weeks	3 (33.3%)
Within last 2 months	2 (22.2%)
Since New Year	4 (44.5%)
Symptoms	
Fever	66.7%
Loss of Consciousness	77.8%
Sunken Eyes	55.6%
Drinking Very Little	11.1%
Dry Mouth	22.2%
Treatment sources	
Hospital	66.7%
Village Health Center	22.2%
No Treatment	11.1%

Frequency of Defecation	2 3x, 1 4x, 1 6x, 5 7x or more
Stool Appearance	
Blood in Stool	11.1%
Mucus/pus in stool	22.2%
Watery Stool	66.7%

Table 2.3.8: Prevalence of Malaria 22

Households/Cases of Malaria	*Malaria Households*
Households	20 (16%)
Cases	22
Average per Household	1.2
Range of Time Ago (days)	1-60
Average of Time Ago (days)	14.15
Ages of patients	
Range	4 mos. to 48 yrs
Average	12.27
Treatment sources	
Hospital	50%
Village Health Center	10%
Village Health Team Volunteer	5%
No treatment	10%
No response	25%

Table 2.3.9: Malaria Prevention Efforts 23

Use of Malaria Nets			
Yes and Adequate	85%	100%	95%
Yes but Inadequate	10%	0%	2%
No	5%	0%	3%
Largest barriers to malaria transmission (multiple answer choices)			
Access to Nets	85%	77.8%	89%
Knowledge about Malaria Transmission	35%	22.2%	29%

Table 2.3.10: Water Statistics 24

% of Self-Reported Boiling of Water	100%	100%	99.2%
% Meeting WHO Standards for Water Purity			
0 colonies	0%	0%	7.1%
1-10 colonies	20%	11.1%	11.9%
% Exceeding 500m to Nearest Water Source by	65%	77.8%	59.5%

Road			

Objective 4: To describe and quantify the treatment-seeking behaviors of residents with household diarrhea cases

Only 9 out of 126 households reported having cases of diarrhea since the beginning of the year (or approximately 6-8 months before survey time). The following results, from the "Diarrhea" section of the self-reported survey, come from exclusively these nine households.

For the 9 households with diarrhea cases, 8 households sought treatment (6 from the local hospital, 2 from the village health center, and 2 additionally from a village health team volunteer). For the one households that did not seek treatment, the diarrhea case went away on its own.

Objective 5: To describe the local understanding of the definition of diarrhea

The following results are taken from the "knowledge of diarrhea" section of the self-reported survey.

Residents stated that the symptoms of diarrhea include: abdominal pain (76%), dehydration (32%), fever (18%), vomiting (18%) and loose and watery stool (13%). In reality, among the cases of diarrhea, the most commonly reported symptoms include loss of consciousness (77.8%), watery stool (66.7%), fever (66.7%), sunken eyes (55.6%) and bloody or mucous stool (33.3%). Thus, there seems to be a disconnect in what residents believe what constitutes diarrhea, and what actually constitutes diarrhea.

Residents stated that the causes of diarrhea include household uncleanliness (42%), eating stale foods (38%), stale drinking water (30%), and bad drinking water (11%).

Treatment options for diarrhea include talking to a doctor/going to the hospital (89%) and oral rehydration salts (24%). In practice, no households with diarrhea cases reported using oral rehydration salts.

C) Goal 3: To investigate field water testing and mapping as a research and data collection strategy, and challenges in using these techniques

Objective 1: To assess the usage of GPS tools as a research instrument

GPS and location data, in conjunction with satellite imagery, is used in this project to primarily accurately measure access to water sources, in terms of direct and road distances. Secondary goals included creating base maps for future research or stakeholder use. The following prose describes the challenges in using GPS as a field research instrument and analyzing location data.

Generally speaking, GPS as a data collection tool is not widespread in epidemiological studies. For example, there is no standardized checklist such as CONSORT for the collection and reporting of location data(Aimone et al., 2013). However, accurate distance data is essential in assessing access to water, and is additionally helpful in visualizing how widespread malaria and diarrhea are as well as the spread of water infrastructure resources. The SODIS study from 2010 used self-reported distance data, but a GPS unit was used in this study to ensure accuracy.

Location data (GPS coordinates) was obtained for all households surveyed, as well as all water sources. Direct distances can be calculated between households and their stated source of water. To facilitate road distances, a map of roads and pathways of the parish was constructed in the ArcMap software using satellite imagery and cross-checked with tracking data from the GPS unit. Both types of distances were used in logistic regression models, as both inputs and outputs.

A number of equipment caveats should be mentioned. The GPS unit used, the Garmin Oregon 550t, is considered to be a recreational (albeit of an advanced level) unit. The accuracy of this unit ranged anywhere from a 1 meter radius to a 10 meter radius, as estimated by the GPS software. More accurate units, however, are prohibitively expensive and thus not feasible. The satellite imagery used to facilitate construction of the roads and pathways map, is the Environmental Systems Research Institute (ESRI) “World Imagery” dataset, with 2.5m SPOT imagery. The possibility exists for extensive tree cover in some areas that block pathways visible to satellites, so some existing pathways could be excluded from the final map.

The biggest challenge to collecting and analyzing GIS field data, however, was the licensing restrictions and internet connectivity requirements of the ArcMap (ArcGIS) software. ArcMap is a very expensive piece of software, and an additional personal-use license is necessary for use of ArcMap offline, for which special permission had to be obtained. The “World Imagery” satellite imagery requires a fast internet connection; there is no legal method to storing the “World Imagery” dataset offline, even with the additional personal-use license.

The learning curve in general for obtaining, storing, and analyzing location data is high, with mastery needed of several separate pieces of software. The Garmin BaseCamp software was used to transfer raw .gpx files to the computer. DNRGarmin, published by the Minnesota Department of Natural Resources, was used to convert these raw files to Shapefiles, which were then opened with ArcMap. To create final products for non-GIS consumption, ArcMap’s kmz converter was used to convert the final map into kmz files, which can then be opened with Google Earth (a freely available, consumer-grade GIS software).

Sharing location data and constructed maps with local stakeholders also proved to be a formidable challenge. ArcMap and BaseCamp are licensed software, however, ArcGIS Explorer and Google Earth are freely available and multiplatform consumer-grade software for viewing finished products. The bigger limitations in sharing are the lack of fast internet connections available to local stakeholders – internet access in the District is primarily through mobile 3G connections, billed a la carte – and equipment requirements for ArcGIS Explorer and Google Earth, which require relatively powerful computers or smartphones.

Finally, while measuring direct distances is relatively straightforward, measuring road distances depends on accurate satellite imagery. In particular, heavily forested areas, and roads or pathways contained within, are difficult to analyze on satellite imagery. A road network was first created on ArcMap by tracing satellite imagery. Then, using the "Network Analyst" extension of ArcMap, which requires a separate license, optimal or shortest road distances were calculated from a household to their stated water source. The procedures for this were figured out in a process of trial and error, and thus the learning curve for using this technique is high.

Objective 2: To assess field water testing logistically as a research instrument

Historically, field water testing has been logistically challenging and expensive. However, as water quality is the primary outcome in this study, water tests are an integral part of the project. The following section describes the challenges encountered in collecting and testing water in the field.

Two water tests were used to assess water safety: nitrate/nitrite indicator strips and 3M Petrifilm *E.coli*/coliform plates. The gold standard in enumerating water bacterial counts is the membrane filtration method, however, this method is unfeasible outside of a proper wet lab environment because of equipment limitations. A small number of field tests are available, including the AquaGenX test, however these tests are both labor intensive and prohibitively expensive.

The 3M Petrifilm plates were initially intended for checking microbiological contamination of food samples, but they have been shown to have medium sensitivity and high specificity as compared to the gold standard. The plates are reasonably priced if bought in bulk, and the learning curve for their use is reasonable. However, use of these plates remain labor intensive, with the time spent each evening inoculating new samples and counting old ones frequently surpassing one hour.

3M defines the proper incubation method as incubating at 37 degrees Celsius for 24 hours, and then 48 hours for follow-up. This, however, is not possible in the field without proper incubators, so the modified field method used is incubation in room temperature (which can vary) for 24 hours, and 48 hours for follow-up.

The enumeration of bacterial colonies for contaminated samples can be difficult, so the heuristic of counting the number of colonies in one average box then multiplying by 20 (the number of boxes on one plate) was used. A counting "app" on a smartphone was used to facilitate enumeration. Data from the plates was used in logistic regression models as outputs.

VIII. Discussion

A) Goal 1: Water, water resources that are available, access to water, water storage and treatment behaviors

The state of water in the parish is complex. In particular, there is a sizeable discrepancy in water quality between water at the source and water at the household point-of-use levels, across all water sources.

The majority of residents have substandard access to water, by any metric. Using the JMP definitions of improved and unimproved water sources, across all villages, 68% of household primarily access unimproved sources of water. At the point-of-use level, only 7.1% of respondents met World Health Organization standards for water purity, with an additional 11.9% with colonies/ml less than 10. Almost 60% of residents are located more than 500m away from their nearest water source. All of these statistics are lower than Uganda-wide and Africa-wide statistics; per the JMP, only 24% of rural residents in all of Uganda use unimproved sources of water.

In villages with access to piped water, the villages closest to the water treatment facility and along the main road, the usage of open springs is slightly decreased to around 56% and the usage of piped water increased to around 30%. Both the figures are still, however, worse than the Uganda-wide and Africa-wide statistics. Both summary statistics and regression results imply that piped water recipients are significantly closer to their water source than are recipients using open springs, however, despite the availability of piped water, it seems that many villagers choose not to use piped water as their primary source, though some households do re-sell their piped water supplies so they made be used as secondary sources. Anecdotally, it seems that those with access to piped water are generally wealthier, with concrete housing and other indirect indicators of wealth.

The cost of piped water, by local standards, is quite high; the monthly water bill of a resident with a private connection is around 15,000 shillings per month, as compared to free water from open springs or boreholes. As part of the wider community partnership, the Duke team funded the installation fees of a piped water connection to a local school with extra funds from our Duke Global Health Institute grant, that cost on the order of hundreds of thousands of shillings (equivalent to the annual salary of a middle or upper class household). This specific piped water connection is intended to provide school students and faculty with clean water; the piped water could also potentially be used by members of the surrounding community, however this researcher does not have information about such usage. Thus, the financial aspect of piped water may be preventing uptake of piped water as a primary water source. More research is needed to assess the financial barriers to piped water uptake, the perceived benefits (or lack thereof) of piped water as understood locally, and the effect of the secondary re-selling of piped water by some households.

What is particularly striking is the discrepancy among bacterial levels at the source and at the household, one that is trending towards significance, across all water sources and types. Almost all households self-reported boiling of water prior to drinking, yet across nearly all households, bacterial counts at the household were higher than counts at the source. This is especially true for the households using primarily piped water. Only one piped water tap was directly measured, but that tap showed no bacterial contamination. Additionally, each time that a tap was used, the water was available on demand, which indicates a relatively high quality piped water system. However, the bacterial counts for piped water users at the point-of-use was actually the highest, per the median, among all types of water at the point-of-use level. These results indicate that there is contamination between the source and point of use, whether it be inadequate boiling or unclean water containers, and that this contamination is more noticeable for users of piped water; further research is needed to pinpoint exactly where this point of contamination is, and on appropriate point-of-use treatment techniques such as adequate boiling.

Using total bacterial level, malaria and diarrhea prevalence as an outcome, regression results suggest that water transport and storage factors (longer distances and longer transportation times, frequency of obtaining water, etc.) are significantly associated with water quality at the household level. In effect, the longer that water is stored (in other words, more stale water), the poorer the quality of water, potentially leading to disease consequences.

As compared to the 2010 data collected for the SODIS feasibility project, the state of water has improved. Both studies were cross-sectional; there is little to no overlap in combined households surveyed. However, these indirect comparisons suggest that the use of unimproved water sources has decreased, as have average distances to primary water sources.

A number of caveats must be considered with the results presented above. The bacteriological counts reported here were derived using the 3M Petrifilm *E.coli/*coliform count plates. Compared to the "gold standard" method of membrane filtration, these plates have been shown to have low sensitivity but high specificity. In other words, the rate of false negatives is high, while the rate of false positives is low; there could be water samples that are contaminated but were not detected using these plates. If anything, the bacterial counts reported here are underestimates of the actual levels of contamination. Additionally, the bacterial counts presented here are the total count of bacteria, of both *Escherichia coli* and coliform counts. *E. coli* counts have been shown to be an accurate predictor of diarrhea, however, certain types of coliforms can have environmental origins. However, coliforms (and any types of bacteria) are good process indicators; point-of-use treatments such as boiling should be able to reduce bacterial counts regardless of origin.

All surveys and field research performed in the parish thus far have occurred during the summer, so seasonal variations, if presents, are not reflected in the data. For water sources, standardized sanitary surveys exist to assess the safety of individual water sources, however these were not performed in this project.

Going forward, climate change, drought, and the ensuing decrease in water availability, will pose new challenges for water safety, especially for the poor and vulnerable. Stanke et al. estimate that drought and climate change will lead to higher concentrations of chemicals and pathogens of water, owing to the lower availability of water. As water sources dwindle, the number of people using each water source will increase, which increases the possibility of pathogen transmission among people. The loss of water will also decrease sanitary standards, particularly leading to poor handwashing, and potential skin and eye infections(Stanke, Kerac, Prudhomme, Medlock, & Murray, 2013).

B) Goal 2: To understand the burden of malaria and diarrhea in the parish, and the water and sanitation factors that could be associated with this burden

Overall, malaria and diarrhea statistics are lower than expected, however, many questions remain about accurately measuring malaria and diarrhea and possible factors in the occurrence of the two diseases.

All malaria indicators suggest a significant decrease in malaria prevalence in the parish, owing in part to a marked increase in the ownership of long-lasting insecticide-treated bed nets, as compared with 2013 data. The number of households reporting malaria cases within the past year decreased in 2014, as compared with 2013 data, and the number of households reported to own at least one net has increased, to the point of being nearly ubiquitous.

Despite the high bacterial counts for most households at the point-of-use, the prevalence of diarrhea in the parish is low. This suggests that residents could have adapted or co-evolved to the presence of these bacteria.

However, self-reported data for both malaria and diarrhea is difficult to verify, and its accuracy is dubious. It may be difficult for respondents to remember cases that occurred earlier in the year. For diarrhea data, the local understanding of the definition of diarrhea (3 or more loose stools a day) may be different, and residents may categorize a diarrhea illness as something else. Thus, malaria and diarrhea prevalence is likely underestimated. However, it still seems plausible that malaria incidence may still have decreased significantly, as there has been a concerted government initiative to distribute free bed nets(Wanzira et al., 2014), and consequently bed net ownership has increased.

Similarly, the accuracy of self-reported sanitation measures such as types of latrines used is dubious. Random spot-checking of latrine status, however, was performed, and the latrines that were checked conformed with the self-reported descriptions provided.

Three households were co-infected with both malaria and diarrhea. Four households reported not using malaria nets, two of which wanted nets but were not able to obtain them from the government during distribution time. Two households reported an inadequate number of nets. None of these households shared any demographic or sanitation characteristics, so further research is needed on these households of interest.

The comparisons of malaria and diarrhea infected households with the study population as a whole revealed a number of discrepancies. For malaria, the discrepancies include: the number and use of bed nets, housing construction type, use of unimproved vs. improved water sources, and types of water containers used. For diarrhea, those discrepancies include: education level, types of housing materials, use of unimproved vs. improved water sources, types of water containers used, water quality, and distances to water source. Additionally, the regression results for both malaria and diarrhea suggest that the frequency of obtaining water is significantly associated (negatively correlated) with disease prevalence, suggesting that water storage or the freshness of water could be a determinant. These factors are potentially significant and should be researched further.

C) Goal 3: To investigate field water testing and mapping as a research and data collection strategy, and challenges in using these techniques

Despite the logistical challenges and equipment constraints, the water testing and mapping data proved invaluable in this project. The most significant findings from this project, the discrepancies in bacterial levels and the road distances to primary water sources, were obtained from water testing and mapping data respectively. In epidemiological surveys, mapping can be a great tool to visualize the spread and intensity of certain indicators, like bacterial counts and disease prevalence. In addition to research uses, mapping can also be a valuable service item, in places that have not been previously mapped.

The use of field water testing and location data as an integral part of an epidemiological project is still rare. Most water testing instruments are both difficult and costly to implement in the field, and researchers generally are not well versed in mapping and the use of mapping as a research tool. No standardized formal evaluation tool or checklist for data reporting, like CONSORT for randomized control trials, is available for either water or location data, so such data, if available, is reported somewhat haphazardly. Going forward, some measure of standardization is needed so that data across studies can be effectively shared and compared.

IX. Conclusion

Access to clean water remains an issue across much of the developing world. Historically, water has been a major influential factor in infectious disease development and spread, particularly with diseases associated with the developing world such as diarrhea and malaria. As countries develop rapidly and clean water infrastructure is expanded, inequalities in clean water uptake are or will also become major issues. Additionally, climate change and the expected increase in drought frequencies will provide new categories of challenges.

Uganda is a rapidly developing country, with a vast array of water resources and options. The parish in Central Uganda where this project took place is a rural parish adjacent to the main market town of the district. The water resources and water use behaviors of residents in this district has previously never before been assessed. As malaria and diarrhea remain broadly major causes of morbidity and mortality in Uganda and across Sub-Saharan Africa, and as the factors surrounding water usage and sanitation remain poorly understood, it was important to research the state of water for this project.

As presented above, we conclude that the water and sanitation-based factors that correlate with malaria and diarrhea outcomes remain poorly understood, however, the prevalence of those outcomes is decreasing, and a number of potential factors warrant further study. The bacterial levels of boreholes at the source exceeds World Health Organization standards. Across all water sources, including piped water, there is an increase in bacterial levels for water at the point-of-use, despite near-universal self-reporting of boiling, suggesting a significant point or points of contamination along the source-use continuum. The state of water in the parish as a whole, including individual villages that have piped water access, lags behind estimated statistics for both Uganda and across Africa in general. Most of the significant findings of this project were derived from the water testing and mapping data, which proved more accurate than the self-reported survey data.

Moving forward, the expansion of piped water across the parish will bring a definitively safe source of water to many households, but the uptake of piped water is slow. More research is needed on the factors influencing piped water uptake and use. Contamination along the source-use continuum remains poorly understood, and it may be necessary to start implementing pilot interventions to address this contamination. Additionally, climate change will bring a whole new set of challenges that will need to be addressed.

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XI. Appendices

A) Survey

Demographics:
Gender: Male____ Female _____
Age: ________
Place of Residence: Parish________ Village____________ Village Letter___________
Last grade of schooling: ________________
Occupation: ______________

Part 1: Household Condition Questions (Coded A)

A1. House Type/Structure (choose one)
- [1] Independent House
- [2] Tenement (Muzigo)
- [3] Independent flat/apartment
- [4] Hut
- [5] Uniport
- [95] Other

A2. What is the major construction material of the roof and/or walls (choose all) ?
- [1] Thatch, straw
- [2] Mud
- [95] Other

[3] Wood, Plants
[4] Iron Sheets
[5] Asbestos
[6] Tiles
[7] Tin
[8] Concrete/Cement

A3. What is the major construction material of the floor (choose all)?

[1] Earth
[2] Earth and cow dung
[3] Cement
[4] Mosaic or tiles
[5] Bricks
[6] Stone
[7] Wood
[95] Other

	A4. How many rooms are in the house?	A7. How many children are in the household?
A4-A7. INSERT NUMBER HERE		

Part 2: Water Access and Sanitation Practices (Coded B)

B0. What do you use water for?

[1] Drinking [2] Bathing [3] Cooking [4] Cleaning [5] Personal Sanitation [95] Other
1 2 3 4 5 95
NOTE: 2, 3, 4, 5, AND 95 ARE "OTHER USES"

B1. Do you obtain water for drinking, and water for other uses, separately?

[0] No [1] Yes
IF NO, PROCEED ONLY TO DRINKING WATER SURVEY (B2-B12)
IF YES, INCLUDE BOTH DRINKING WATER AND WATER FOR OTHER USES SURVEY (B12 ONWARDS)

Drinking Water Survey

	B2. What are your top two sources of drinking water?	B3. How often do you obtain drinking water per week INSERT NUMBER HERE	B4. How much time (in minutes) do you spend fetching water each trip? INSERT NUMBER HERE	B5. Do you use any of the following to obtain water? [1] Walking [2] Biking [3] Motor Transportation	B6. Do you pay for your water? [0] No [1] Yes	B7. If yes to B6, how much do you pay for your water? INSERT NUMBER HERE
Private Connection/Piped Water	1			1 2 3	0 1	
Public Tap	1			1 2 3	0 1	
Bore-hold	1			1 2 3	0 1	
Protected well/spring	1			1 2 3	0 1	
Unprotected well/spring	1			1 2 3	0 1	
River, stream, lake, pond	1			1 2 3	0 1	
Vendor/Tanker Truck	1			1 2 3	0 1	
Other (Please specific) __________	1			1 2 3	0 1	

B8. Do you do anything to the water prior to drinking (choose one)?

[1] Boil and filter
[2] Boil only
[3] Filter only
[4] Nothing
[95] Other

	B9. Where do you store your drinking water?	B10. Is this container of drinking water covered? [0] No [1] Yes	B11. Is this container of drinking water elevated (i.e. on a shelf?)? [0] No [1] Yes	B12. How often do you clean your water storage containers (per month)? INSERT NUMBER HERE
1 Pot	1	0 1	0 1	
2 Jerry Can	1	0 1	0 1	
3 Saucepan	1	0 1	0 1	
4 Drums	1	0 1	0 1	
5 Jug/Kettle	1	0 1	0 1	
95 Other	1	0 1	0 1	
6 Bottle/Flask				
7 Bucket				

	B24. Where do you defecate?	B25. Is there a hand-washing facility at this place? [0] No [1] Yes (b=bottle of water, j=jerry can)
1 Covered Pit Latrine Private	1	0 1
2 Covered Pit Latrine Shared	1	0 1
3 VIP latrine private	1	0 1
4 VIP latrine shared	1	0 1
5 Uncovered pit latrine (private or shared)	1	0 1
6 Flush toilet private	1	0 1
7 Flush toilet shared	1	0 1
8 Bush	1	0 1
95 Other	95	0 1
96 None/don’t know	96	0 1

B26. Do you use any of the following when you wash your hands?
[1] Commercially-available soap [2] Hand sanitizer [3] Home-made Soap [95] Other
1 2 3 95

B27. Do you keep domestic animals within the house?
[0] No
[1] Yes
IF YES, PROCEED TO B28.

IF NO, PROCEED TO B29.

B28. If so, what types of animals to you keep within the house?

[1] Goats	[2] Pigs	[3] Cows	[4] Chickens	[95] Other
1	2	3	4	95

	B30. Have you received public health messages about:	B31. What were the major changes you made in your house because of these messages? [1] Use tap water [2] Stop open defecation [3] Use individual household latrine [4] Wash hands with soap regularly [5] Safely handle and store drinking water [6] Boil, filter, or treat drinking water [95] Other [96] None
1 Hand washing	1	1 2 3 4 5 6 95 96
2 Water storing and treating	1	1 2 3 4 5 6 95 96
3 Personal hygiene	1	1 2 3 4 5 6 95 96
4 Sanitation/excreta management	1	1 2 3 4 5 6 95 96
95 Other	95	1 2 3 4 5 6 95 96
96 None/Don’t know	96	1 2 3 4 5 6 95 96

Part 3: Knowledge of Diarrhea (Coded C)

	C1. In your opinion, what are the symptoms of diarrhea (check all the apply)?
1 Loose and watery stool	1
2 Blood/mucus in stool	1
3 Abdominal pain	1
4 Soft part (on skull of a toddler) sunken	1
5 Fever	1
6 Vomiting	1
7 Weakness	1

8 Dehydration	1
9 Loss of sense	1
10 Headache	1
11 Constipation	1
12 Other	95
13 Don’t know/not sure	96

	C2. What are the causes or reasons for diarrhea?
1 Eating stale foods	1
2 Eating food not made in own home	1
3 Eating food touched by insects	1
4 Unclean/smelly food	1
5 Drinking bad water	1
6 Using unhygienic latrines/open defecation	1
7 Open drains/bad drainage	1
8 Not washing hands	1
9 Bad weather/weather change	1
10 Exposure to sun	1
11 Drinking water is not fresh	1
12 Changing of water source	1
13 Household uncleanliness	1
14 Village uncleanliness	1
95 Other	95
96 Don’t know/not sure	96

	C3. How do you treat a child who has diarrhea?
1 No treatment	1
2 Use oral re-hydration salts/solution	1
3 Take certain foods	1
4 Avoid certain foods	1
5 Use traditional medicine	1
6 Talk to a doctor/go to hospital	1
7 Talk to a village health worker	1
95 Other	95
96 Don’t know/not sure	96

Part 4: Prevalence of Diarrhea (Coded D)

D1. When was the last time your child had 3 watery stools without blood, within a day (choose one)?

[1] Within the last 3 weeks
[2] Within the last 2 months
[3] Since the beginning of the year (New Year’s Day)

	D2. Did you notice any of the following signs during the diarrheal period in your child? [1] Fever [2] Loss of Consciousness [3] Sunken Eyes [4] Incapable of drinking/drinking very little [5] Dry Mouth [6] Thirsty [7] Decreased urination [8] Wrinkled skin [9] Lethargy [95] Other [96] None/Don't know	D3. When your child was sick with diarrhea, on average, how many times did your child defecate per day? INSERT NUMBER HERE	D4. When your child had diarrhea, what did his/her stool look like? [1] Blood in stool [2] Mucus/pus in stool [3] Watery Stool	D5. When your child had diarrhea, did you seek treatment from a VHT? [0] No [1] Yes
Last time child had diarrhea	1 2 3 4 5 6 7 8 9 95 96		1 2 3	0 1

	D6. Did you attempt to seek any help when your child had diarrhea? IF YES, PROCEED TO D7 IF NO, PROCEED TO D8 [0] No [1] Yes	D7: If So, where? SKIP D8 and D9 [1] Government Hospital [2] Village Health Center [3] Private Hospital [4] Private Doctor/Nurse/Midwife/Clinic [5] NGO Distributor [6] Religious Institution [7] Friend/Relative [8] Traditional Healer	D8. If not, why? [1] Financial inability [2] Distance [3] Spontaneous Recovery [95] Other	D8. If not, what other resources did you try to use or access? [1] Self-Medicine [2] Oral Rehydration Salts [3] Zinc supplements [95] Other [96] None
Last time child had diarrhea	0 1	1 2 3 4 5 6 7 8	1 2 3 95	1 2 3 95 96

	D9. Did you take any special precautions with water during diarrhea, outside of normal drinking water	D10. If so, what precautions did you take? [1] Boil	D11. What did you use water for when your child was sick with diarrhea?

	precautions? IF YES, PROCEED TO D10 IF NO, PROCEED TO D11 [0] No [1] Yes	[2] Bleach/chlorine [3] Strain through cloth [4] Filter [5] Stand and settle [95] Other [96] None/Don’t know	[1] As drinking water [2] As water for comfort [3] To make home-made medicines [95] Other [96] None/Don’t know
Last time child had diarrhea	0 1	1 2 3 4 5 95 96	1 2 3 4

Part 5: Malaria Follow-Up (Coded E)

E1. How many cases of malaria has your family had in the past year?
[0] None
[1] 1 or more: Please specify _____________
IF [0], PROCEED TO E5
IF [1], PROCEED TO E2

	E2. If there was/were cases, what was the gender and age of the patient, for each case? GENDER: M OR F AGE: ENTER NUMBER	NOTE: CODE [C] FOR CHILD HERE IF APPLICABLE (<18 yrs old)	E3. If there were cases of malaria, did you seek treatment from a VHT? [0] No [1] Yes IF [0] PROCEED TO E5 IF [1] PROCEED TO E4	E4. If so, was medicine given by the VHT? [0] No [1] Yes
Case 1			0 1	0 1
Case 2			0 1	0 1
Case 3			0 1	0 1
Case 4			0 1	0 1
Case 5			0 1	0 1

E5. Do you use a malaria net? (Note: use as in actively use, not just own)
[0] No
[1] Yes
[2] Yes but inadequate/not enough nets
IF NO, PROCEED TO E6
IF YES, PROCEED TO E7

E7. If you do use a net, is it treated with insecticides? If so, when was it last treated?

[0] No
[1] Yes, specify time frame/months or years ago _________
[96] Don't know

E8. If you do use a net, how is it hung up in the household (choose one)?

[1] Tied to the wall and covering the bed
[2] Partially tied to the wall
[95] Other

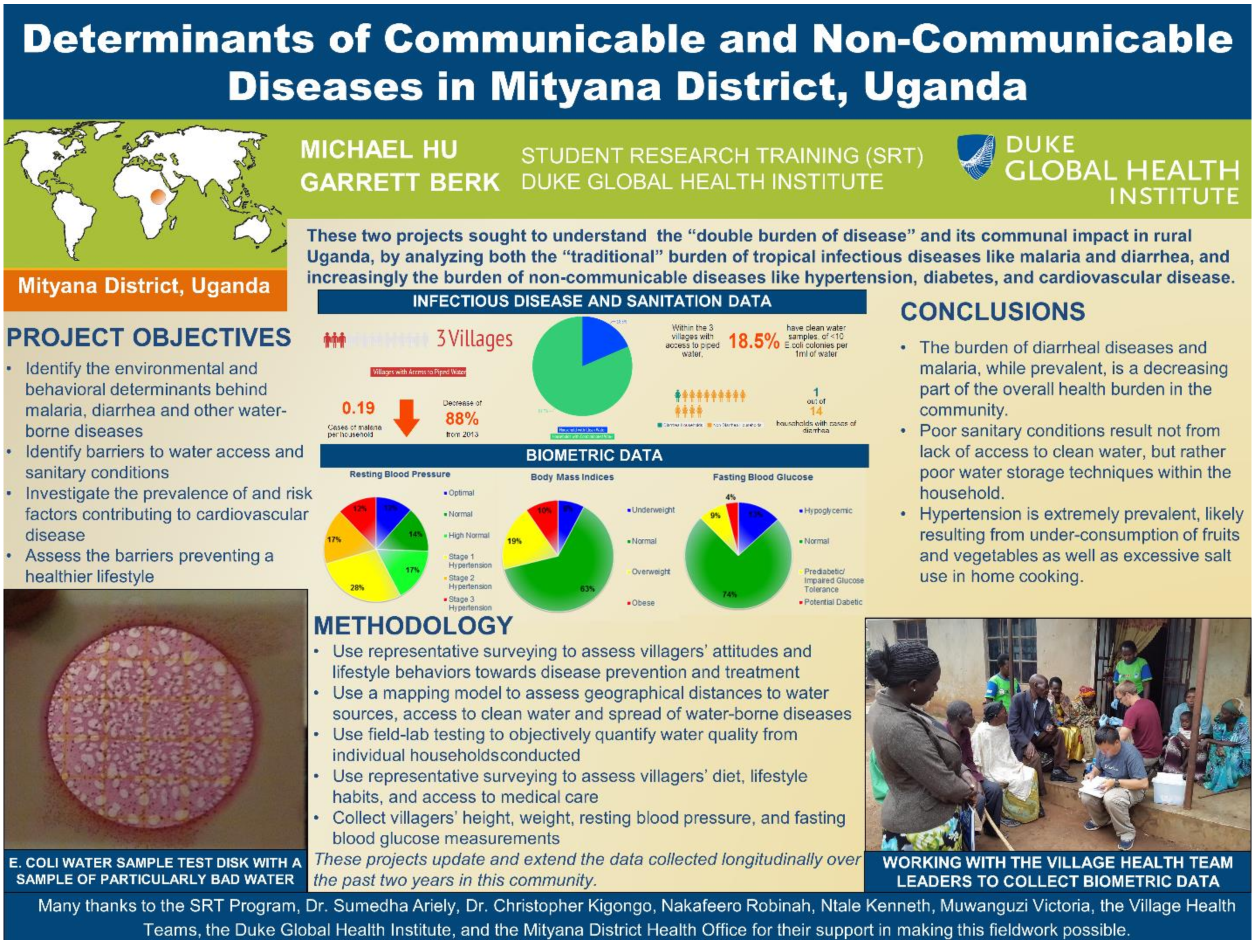
E9. Do you sleep under the net consistently; is it hung up all the time? If not, why not?

[0] No
[1] Yes

E10. What do you think is the largest barrier to preventing malaria transmission (choose one)?

[1] Access to anti-malarial drugs
[2] Access to nets
[3] Knowledge about the transmission of malaria
[95] Other
[96] None/Don't know

B) Duke Global Health Institute Showcase Poster (Communicable and Non-Communicable Diseases Combined)



Determinants of Communicable and Non-Communicable Diseases in Mityana District, Uganda

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DUKE GLOBAL HEALTH INSTITUTE

DUKE GLOBAL HEALTH INSTITUTE

Mityana District, Uganda

These two projects sought to understand the "double burden of disease" and its communal impact in rural Uganda, by analyzing both the "traditional" burden of tropical infectious diseases like malaria and diarrhea, and increasingly the burden of non-communicable diseases like hypertension, diabetes, and cardiovascular disease.

PROJECT OBJECTIVES

- Identify the environmental and behavioral determinants behind malaria, diarrhea and other water-borne diseases
- Identify barriers to water access and sanitary conditions
- Investigate the prevalence of and risk factors contributing to cardiovascular disease
- Assess the barriers preventing a healthier lifestyle

INFECTIOUS DISEASE AND SANITATION DATA

BIOMETRIC DATA

CONCLUSIONS

- The burden of diarrheal diseases and malaria, while prevalent, is a decreasing part of the overall health burden in the community.
- Poor sanitary conditions result not from lack of access to clean water, but rather poor water storage techniques within the household.
- Hypertension is extremely prevalent, likely resulting from under-consumption of fruits and vegetables as well as excessive salt use in home cooking.

METHODOLOGY

- Use representative surveying to assess villagers' attitudes and lifestyle behaviors towards disease prevention and treatment
- Use a mapping model to assess geographical distances to water sources, access to clean water and spread of water-borne diseases
- Use field-lab testing to objectively quantify water quality from individual householdsconducted
- Use representative surveying to assess villagers' diet, lifestyle habits, and access to medical care
- Collect villagers' height, weight, resting blood pressure, and fasting blood glucose measurements

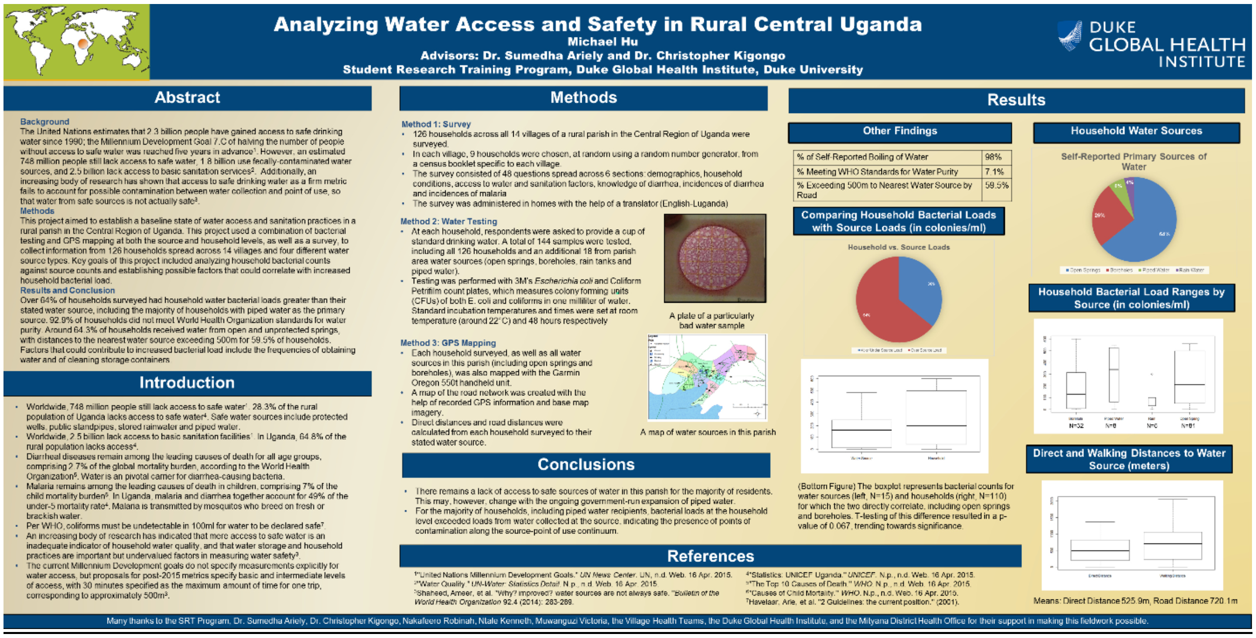
These projects update and extend the data collected longitudinally over the past two years in this community.

E. COLI WATER SAMPLE TEST DISK WITH A SAMPLE OF PARTICULARLY BAD WATER

WORKING WITH THE VILLAGE HEALTH TEAM LEADERS TO COLLECT BIOMETRIC DATA

Many thanks to the SRT Program, Dr. Sumedha Ariely, Dr. Christopher Kigongo, Nakafeero Robinah, Ntale Kenneth, Muwanguzi Victoria, the Village Health Teams, the Duke Global Health Institute, and the Mityana District Health Office for their support in making this fieldwork possible.

C) Visible Thinking Poster



Analyzing Water Access and Safety in Rural Central Uganda

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Abstract

Background
The United Nations estimates that 2.3 billion people have gained access to safe drinking water since 1990; the Millennium Development Goal 7.C of halving the number of people without access to safe water was reached five years in advance[1]. However, an estimated 748 million people still lack access to safe water, 1.8 billion use fecally-contaminated water sources, and 2.5 billion lack access to basic sanitation services[2]. Additionally, an increasing body of research has shown that access to safe drinking water as a firm metric fails to account for possible contamination between water collection and point of use, so that water from safe sources is not actually safe[3].

Methods
This project aimed to establish a baseline state of water access and sanitation practices in a rural parish in the Central Region of Uganda. This project used a combination of bacterial testing and GPS mapping at both the source and household levels, as well as a survey, to collect information from 126 households spread across 14 villages and four different water source types. Key goals of this project included analyzing household bacterial counts against source counts and establishing possible factors that could correlate with increased household bacterial load.

Results and Conclusion
Over 64% of households surveyed had household water bacterial loads greater than their stated water source, including the majority of households with piped water as the primary source. 92.9% of households did not meet World Health Organization standards for water purity. Around 64.3% of households received water from open and unprotected springs, with distances to the nearest water source exceeding 500m for 59.5% of households. Factors that could contribute to increased bacterial load include the frequencies of obtaining water and of cleaning storage containers.

Introduction

- Worldwide, 748 million people still lack access to safe water[1]. 28.3% of the rural population of Uganda lacks access to safe water[4]. Safe water sources include protected wells, public standpipes, stored rainwater and piped water.
- Worldwide, 2.5 billion lack access to basic sanitation facilities[1]. In Uganda, 64.8% of the rural population lacks access[4].
- Diarrheal diseases remain among the leading causes of death for all age groups, comprising 2.7% of the global mortality burden, according to the World Health Organization[5]. Water is an pivotal carrier for diarrhea-causing bacteria.
- Malaria remains among the leading causes of death in children, comprising 7% of the child mortality burden[6]. In Uganda, malaria and diarrhea together account for 49% of the under-5 mortality rate[4]. Malaria is transmitted by mosquitos who breed on fresh or brackish water.
- Per WHO, coliforms must be undetectable in 100ml for water to be declared safe[7].
- An increasing body of research has indicated that mere access to safe water is an inadequate indicator of household water quality, and that water storage and household practices are important but undervalued factors in measuring water safety[3].
- The current Millennium Development goals do not specify measurements explicitly for water access, but proposals for post-2015 metrics specify basic and intermediate levels of access, with 30 minutes specified as the maximum amount of time for one trip, corresponding to approximately 500m[3].

Methods

Method 1: Survey
- 126 households across all 14 villages of a rural parish in the Central Region of Uganda were surveyed.
- In each village, 9 households were chosen, at random using a random number generator, from a census booklet specific to each village.
- The survey consisted of 48 questions spread across 6 sections: demographics, household conditions, access to water and sanitation factors, knowledge of diarrhea, incidences of diarrhea and incidences of malaria
- The survey was administered in homes with the help of a translator (English-Luganda)

Method 2: Water Testing
- At each household, respondents were asked to provide a cup of standard drinking water. A total of 144 samples were tested, including all 126 households and an additional 18 from parish area water sources (open springs, boreholes, rain tanks and piped water).
- Testing was performed with 3M's *Escherichia coli* and Coliform Petrifilm count plates, which measures colony forming units (CFUs) of both E. coli and coliforms in one milliliter of water. Standard incubation temperatures and times were set at room temperature (around 22°C) and 48 hours respectively

A plate of a particularly bad water sample

Method 3: GPS Mapping
- Each household surveyed, as well as all water sources in this parish (including open springs and boreholes), was also mapped with the Garmin Oregon 550t handheld unit.
- A map of the road network was created with the help of recorded GPS information and base map imagery.
- Direct distances and road distances were calculated from each household surveyed to their stated water source.

A map of water sources in this parish

Conclusions

- There remains a lack of access to safe sources of water in this parish for the majority of residents. This may, however, change with the ongoing government-run expansion of piped water.
- For the majority of households, including piped water recipients, bacterial loads at the household level exceeded loads from water collected at the source, indicating the presence of points of contamination along the source-point of use continuum.

Results

Other Findings

% of Self-Reported Boiling of Water	98%
% Meeting WHO Standards for Water Purity	7.1%
% Exceeding 500m to Nearest Water Source by Road	59.5%

Comparing Household Bacterial Loads with Source Loads (in colonies/ml)

(Bottom Figure) The boxplot represents bacterial counts for water sources (left, N=15) and households (right, N=110) for which the two directly correlate, including open springs and boreholes. T-testing of this difference resulted in a p-value of 0.067, trending towards significance.

Household Water Sources

Household Bacterial Load Ranges by Source (in colonies/ml)

Direct and Walking Distances to Water Source (meters)

Means: Direct Distance 525.9m, Road Distance 720.1m

References

[1] "United Nations Millennium Development Goals." *UN News Center*. UN, n.d. Web. 16 Apr. 2015.
[2] "Water Quality." *UN-Water: Statistics Detail*. N.p., n.d. Web. 16 Apr. 2015.
[3] Shaheed, Ameer, et al. "Why? improved? water sources are not always safe." *Bulletin of the World Health Organization* 92.4 (2014): 283-289.
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[5] "The Top 10 Causes of Death." *WHO*. N.p., n.d. Web. 16 Apr. 2015.
[6] "Causes of Child Mortality." *WHO*. N.p., n.d. Web. 16 Apr. 2015.
[7] Havelaar, Arie, et al. "2 Guidelines: the current position." (2001).

Many thanks to the SRT Program, Dr. Sumedha Ariely, Dr. Christopher Kigongo, Nakafeero Robinah, Ntale Kenneth, Muwanguzi Victoria, the Village Health Teams, the Duke Global Health Institute, and the Mityana District Health Office for their support in making this fieldwork possible.

D) 3M Petrifilm *E.Coli/*Coliform Interpretation Resources

- Petrifilm Product Page from 3M, with links to brochures, usage guides, interpretation guides, case studies, and regulatory information: http://www.3m.com/3M/en_US/company-us/all-3m-products/~/3M-Petrifilm-E-coli-Coliform-Count-Plates?N=5002385+8709314+8710780+8711017+8711295+8711414+8711726+8716589+8716609+3293785155&rt=rud
- Sale Product Page from Nelson Jameson: http://nelsonjameson.com/3M-Petrifilm-E-coli-Coliform-Count-Plates-p2028.html