2018

Waterborne Disease Reduction Using Evidence-based Microbiology Verification in Lower Nyakach, Kenya

Richard R. Blodgett
Walden University

Walden University

College of Health Sciences

This is to certify that the doctoral dissertation by

Richard R. Blodgett

has been found to be complete and satisfactory in all respects,
and that any and all revisions required by
the review committee have been made.

Review Committee
Dr. Talmage Holmes, Committee Chairperson, Public Health Faculty
Dr. Peter Anderson, Committee Member, Public Health Faculty
Dr. Mehdi Agha, University Reviewer, Public Health Faculty

Chief Academic Officer
Eric Riedel, Ph.D.

Walden University
2018

Abstract

Waterborne Disease Reduction Using Evidence-based Microbiology

Verification in Lower Nyakach, Kenya

by

Richard R. Blodgett

Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Philosophy

Public Health – Epidemiology

Walden University

August 2018

Abstract

Waterborne diseases continue to plague the poorest people in low-income countries and are estimated to cause 4,600,000 acute incidents of diarrhea resulting in over 2,000 deaths daily. A major challenge is performing microbiology tests to monitor drinking water quality. Friends of the Old (FOTO) implemented a novel strategy using evidence-based microbiology to educate communities about the relationship between contaminated water and disease. Two commercially available tests for *E.coli,* adapted for fieldwork, provided easily interpreted results of contamination that correlate with WHO's disease risk categories. Simple and effective household water treatment options–solar pasteurization and/or chlorination–were provided to all 14,400 families and 42 schools in Lower Nyakach, Kenya. From February to May, 2015, adjacent districts had serious cholera outbreaks, but in Lower Nyakach, where education and the use of chlorine were nearly universal, there were no cases of cholera and steadily decreasing rates of diarrhea. A cross-sectional study was conducted to verify self-reported water treatment practices with evidence-based microbiological testing. A random sample of 377 households revealed that 95% treat their water each and every time they collect. Microbiological verification found 96% of household safe water storage vessels were low risk compared to their very high risk source water. A strong association ($p < 0.001$) existed between the observed decrease in diarrhea trends from health facilities in Lower Nyakach and exposure to the novel training. The strategy used by FOTO could be replicated to empower communities worldwide to identify contaminated drinking water sources and to reduce the incidence of waterborne disease.

Waterborne Disease Reduction Using Evidence-based Microbiology

Verification in Lower Nyakach, Kenya

by

Richard R. Blodgett

Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Philosophy

Public Health – Epidemiology

Walden University

August 2018

Dedication

To Professor Robert H. Metcalf, scientist, educator, and humanitarian who always taught, by example, that ‘good science should improve the human condition.

Acknowledgments

The author gratefully acknowledges the valuable contributions of:

Dr. Talmage Holmes, Dissertation Committee Chair, mentor and friend. Dr. LaToya Johnson, dissertation committee member, Dr. Peter Anderson, dissertation committee member, Carla Remund, Katy Blodgett, Jeff Blodgett, Gary Hulbert, Sam Herrington, and Tim Mortensen for document review and technical support.

The Kenyan FOTO Staff: Antony Chienjo, GIS mapping project coordinator, Michael Chienjo, data collection project coordinator, Joseph Abende, Felix Ogutu and John Amayo. GIS Mapping Interns and Survey Specialists: Dickens Sigo Hongo, Calvin Opiyo Kalama, John Onyango Omom, Michael Ochuka, Josua Abayo Agola, Brian Onyango Odhiambo, Evance Andiwo, Joseph Otieno Osawo, Paul Otieno Oking, Tobias Onyango Nyakoko, Emmaculate Awuor, Linet Akinyi, Joyce Achieng', Everlyn Erca Okutto, Steve Opiyo, Dickens Ochieng', Susan Awino, and Seline Osian.

FOTO Village Access Facilitators: Brigitta Ondiek, Mary Otieno, Carren Awino, Pamela Otieno, Seline Osian, Martha Omondi, Rebecca Okore, Plista Ouma, Ruth Hongo, Margaret Aloo, Florence Okoyo, and Margaret Omolo.

Bright Water Foundation Board of Directors, advisors and staff, and to my family who did sacrifice and support this effort from conception to completion.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction to the Study

The United Nations declared 2005-2015 as the International Decade for Action: Water for Life. The adoption of Millennium Development Goal 7, Target C (MDG 7C), which aimed to reduce by one-half the proportion of the world's population without access to safe drinking water and sanitation, was met in 2010, but concerns about the quality and safety of many improved drinking water sources persist (Onda, LoGuglio, & Bartram, 2012). Improved drinking water technologies such as piped water, public standpipes and boreholes, protected dug wells or springs, and even rainwater collection are more likely to provide safe drinking water than those characterized as unimproved (WHO/UNICEF, 2015). However, due to the difficulty in verifying safe drinking water at the household level, many more people than originally estimated drink unsafe water from improved sources (Bain et al., 2011).

In 2011, 83% of the population lacked access to an improved drinking water source lived in rural communities; yet, despite the unprecedented progress of providing improved drinking water sources to more than 2.1 billion people, an estimated 768 million still drew water from an unimproved source (United Nations, 2013). The lack of safe water contributes to the approximately 4 billion cases of diarrhea and about 1.8 million deaths every year in developing countries (WHO, 2014). Of these deaths, 90% are of children under 5, which accounts for 19% of total child deaths secondary only to respiratory infections.

Since 2012, Friends of the Old (FOTO) a community-based organization in Lower Nyakach, Kenya, has developed a novel strategy using evidence-based microbiology to reduce diarrhea morbidity. Initial reports from the district hospital and health clinics demonstrated a substantial decrease in diarrhea disease (see Table 1).

Table 1

Katito Health Centre, Central Location Lower Nyakach, 2012

Month	Families provided with WaterGuard	Disease Cases		
		Clinical Malaria	Diarrhea	Typhoid Fever
January	0	256	145	18
July	400	196	46	13
November	800	319	30	0

I conducted an impact evaluation to explore the association of the observed decrease of diarrheal admissions to the health clinics of Lower Nyakach with the advent of a novel strategy to reduce waterborne infectious disease using evidence-based microbiology in a community-based organization. Practicality of the novel FOTO strategy may encourage adoption of this intervention by nongovernmental and government agencies, leading to significant improvements in public health throughout Kenya, Africa, and the developing world.

This chapter provides a brief synopsis of the literature background and its impact on the purpose, questions, and hypothesis for this study. I then explain the nature of the study, including the risk assessment approach and why cross-sectional designs are best to address diarrheal disease in developing countries. I also describe the scope and limitations of this proposal to establish the boundaries of the study area, population, and method of data collection to address issues of validity and generalizability. The chapter will conclude with a summary and an overview table of the variables to be tested and their corresponding measurement scale and values.

Background

The Joint Monitoring Programme (JMP) between WHO and UNICEF reports on the use of “improved” sources because current surveys do not provide reliable information on the quality of drinking water, either at the source or in households (WHO, 2013). The element that is missing in most water programs is the ability to verify that the target bacteria are being reduced or eliminated. The literature will demonstrate why *E. coli* is the best indicator of fecal pollution (Allen, Payment, & Clancy, 2010; Edberg, Rice, Karlin, & Allen, 2000; Standridge, 2008) and correlates with (WHO/UNICEF, 2012) disease risk categories and Medecins Sans Frontieres (1994) priority for action (see Table 2), thus replacing the less reliable and costly thermotolerant coliform test as a rapid detection indicator (Edberg et al., 2000; Doyle & Erickson, 2006). A simple and effective portable microbiology laboratory (PML) developed by Metcalf (2010) using commercially available items enables water testing at the community level to determine the disease risk of source samples.

A review of interventions to improve water quality for preventing diarrhea was conducted by the Cochrane Collaboration (Clasen, Roberts, Rabie, Schmidt, & Cairncross, 2006). The conclusions of this meta-analysis report were that interventions to improve the microbiological quality of drinking water, especially at the household level, are more effective in preventing diarrheal morbidity than was previously reported by Fewtrell et al. (2005) and Esray and Habicht (1986). In the case of water quality improvements, Esray and Habicht (1986) cited a median reduction of 16% in diarrheal disease from nine studies. Globally, WHO reports a 40% decrease in years of life lost (YLL) due to diarrhea from 2000-2012 (WHO, 2014).

Point-of-use interventions are fast becoming the treatment of choice for improving household water quality (DuBois, et al., 2010; Preez, et al., 2008; WHO, 2013). The Safe Water System (SWS) developed by CDC and Pan American Health Organization/WHO, is a simple, inexpensive, point-of-use household water quality intervention using locally produced chlorine bleach for water treatment, ceramic safe storage containers with a narrow mouth and tight fitting lid to prevent re-contamination and behavioral change communications. There is a plethora of literature demonstrating the varying success of SWS (Arnold & Colford, 2007; Clasen et al., 2006; Fewtrell et al., 2005; Waddington & Snilstveit, 2009). The SWS provides grounding for FOTO's evidence-based microbiological approach to home water treatment and storage (HWTS) interventions. The two main methods for treating water at the household level, utilized in this study, are solar water pasteurization using free energy from the sun (Ciochetti & Metcalf, 1984) , and inexpensive chlorine dosing of source water collections (Alekal, 2005; Lantange, 2008).

Participatory Hygiene and Sanitation Transformation (PHAST) is a theoretical design to promote hygiene behaviors and community management using participatory techniques. The basis of the approach is that lasting social change in people's behavior of the adoption of a health intervention will not occur without their understanding and believing (Simpson-Hebert, Sawyer, & Clarke, 2000).

Community Led Total Sanitation studies indicate that information and motivation alone are not sufficient to increase adoption of hygienic practices (Guiteras, Levinsohn, & Mobarak, 2015). The literature suggests that product price is a primary barrier to adoption of health products and that subsidies targeted to the poor coupled with community motivation may lead to significant adoption (Onjala, Ndiritu, & Stage, 2014).

The novel FOTO project strategy of involving communities in evidence-based microbiology testing of water sources and providing inexpensive treatment options to impoverished families has reduced the burden of waterborne disease in Lower Nyakach (R.H. Metcalf, personal communication, July 12, 2016). The concept that “seeing is believing” may change drinking water treatment behavior in a community (Simpson-Hebert et al., 2000). The evidence-based microbiology approach provides visual verification of waterborne disease indicators that help communities understand the connection between stomach illness and water contamination (Chienjo, 2013).

Problem Statement

The MDG 7C drinking water target relies on the classifications of water sources as “improved” or “unimproved” as proxy indicators for water safety (WHO/UNICEF, 2010a). Water quality monitoring is often a missing factor in programs to improve access to safe drinking water in developing countries, despite being the most important parameter to test from a public health standpoint.

Treatment and testing of water is seldom carried out in places where water supplies are community managed, as is often the case in slums, peri-urban and rural areas (WHO, 2008; WHO/UNICEF, 2010a). Interventions aimed at improving the microbiological safety of drinking water by inactivating or removing waterborne pathogens has been limited to the extent that laboratory facilities and microbiological expertise are available to test the efficacy of the intervention (Onda et al., 2012). Household safe water storage and protection is uncertain without microbial safety verification (Levy et al., 2012; WHO/UNICEF, 2013).

There is a need in low-income countries for a rapid, easy to teach and use field testing for the detection of *E.coli* in drinking water (Allen, 2010; WHO, 2013).

Purpose of the Study

The purpose of this quantitative study was to evaluate the efficacy of a novel approach to reduce waterborne disease in a community-based program using evidence-based microbiology. The dependent variable for this study was the change in diarrhea morbidity from the reported case admissions from the Pap Onditi District Hospital, Katito health center, and Kibogo dispensary records, 3 years prior to and 3 years after introduction of the intervention.

The main independent variable was the WHO level of risk for contracting a waterborne infectious disease (see **Error! Reference source not found.**). Additional independent variables evaluated were the study participants' possession of a SWS storage vessel, the method of treatment used, and the frequency of treatment.

Other independent variables I explored were the type of SWS vessels used, source of the drinking water, the participants' self-report of drinking water safety, and the time since the participant was exposed to the novel training of the evidence-based microbiology approach.

Covariate variables included testing microbiological water quality of on-site household SWS storage vessels for chlorine residual. Directly observed measurements of chlorine residual in stored water have been used as proxy indicators of behavior interest in SWS studies (Barzilay et al., 2011; Fiebelkorn et al., 2012) but, despite their proven effectiveness, these measurements have not changed the adoption of point-of-use water treatment to sufficient scale to permit assessments of health impacts (Clasen et al., 2006). In this study, I used residual chlorine results to help determine the proper usage of the disinfectant by study participants in relation to dose versus time concentration.

A contributing variable was the exposure of the head of household to the educational portion of the intervention, namely the evidence-based microbiological method utilizing the PML and training on chlorine use and solar pasteurization techniques by trained FOTO personnel. The results of this impact evaluation were compared to other safe water interventions as determined by the Cochrane Collaboration study by Clasen et al. (2006). Because of multiple pathways of diarrheogenic infection, improvements in water quality alone may not necessarily interrupt disease transmission, thus JMP household surveys were conducted to determine the level of sanitation practices and water treatment habits in the community.

Research Question and Hypothesis

Initial reports from the district hospital in Pap Onditi, Kenya, which serves the Lower and Upper Nyakach regions, showed a 40-73% decrease in diarrhea since the introduction of the FOTO project intervention using evidence-based microbiology in 2012 (see Figure 1). In February 2015, in the midst of a major cholera outbreak in the neighboring counties and nearby districts, Lower Nyakach had no reported cases of cholera. On a fact-finding visit to Lower Nyakach in July 2015, anecdotal reports from FOTO staff and village elders indicated an 89-90% acceptance and use rate of household chlorination and solar pasteurization of drinking water by the 14,000 families in Lower Nyakach (Personal communication, July 6 2015).

Pap Onditi Hospital Diarrhea Trend

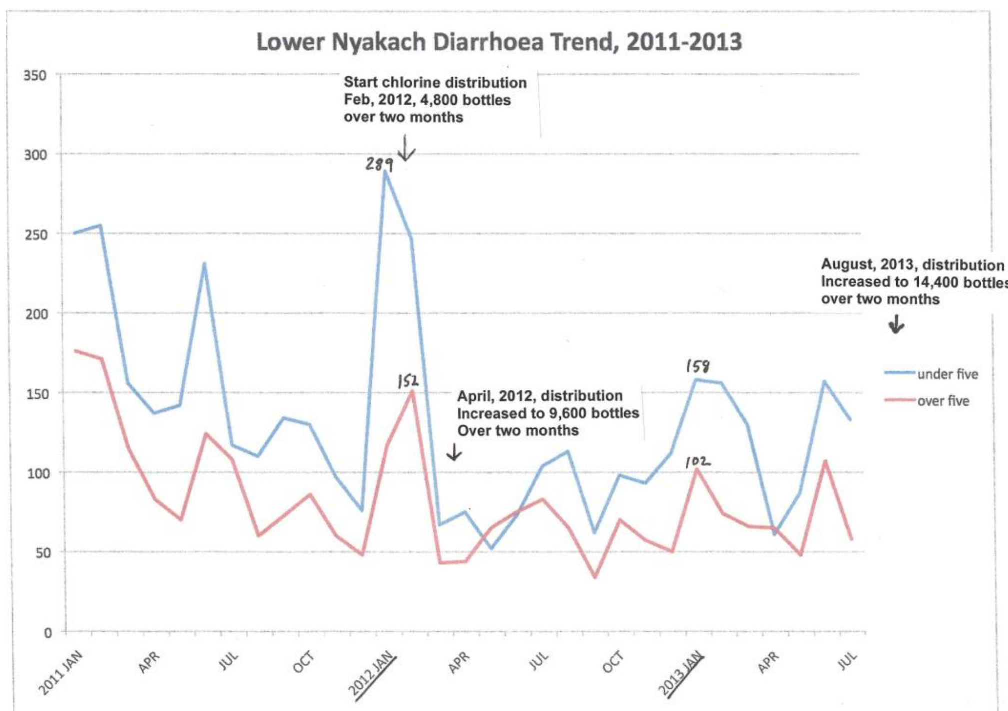


Figure 1. Pap Onditi Hospital diarrhea trend
Courtesy, Nyando District Hospital, 2013

The overarching question I addressed with this study is whether an association exists with this observed decrease in diarrhea morbidity and the advent of the novel evidence-based microbiology intervention by FOTO using the PML? The research questions (RQs) were as follows:

RQ1: Is there an association between the change in diarrhea morbidity in Lower Nyakach, Kenya, and the novel evidence-based microbiology intervention?

RQ2: Is there an association in WHO risk of waterborne disease and the possession of a safe water vessel?

RQ3: Is there a difference in WHO risk between solar pasteurization users and chlorine bleach users?

The null hypothesis was that there would be no observed association between a decrease in diarrheal prevalence and the HWTS methods, chlorine disinfection and/or solar water pasteurization to reduce WHO risk of disease, among participants of the FOTO study. The alternative hypothesis was that an association exists between a reduction in diarrhea morbidity and the use of HWTS methods among study participants using FOTO's evidence-based microbiology verification approach.

Theoretical Framework for the Study

The Participatory Hygiene and Sanitation Transformation (PHAST) theory, as explained by Simpson-Hebert et al., (2000), is an innovative approach positing that change in people's behavior towards sanitation and hygiene will not occur without their understanding and believing. Community-led sanitation and hygiene programs are less effective without behavioral change communications (Etheridge, 2015). In Chapter 2, I will explain in greater detail how PHAST helped me to gain a better perspective of behavioral change concepts that have permeated the Nyanza Province and other areas throughout Kenya and Africa.

Behavioral change communications are at the core of FOTO's unique strategy to eliminate waterborne disease in Lower Nyakach. The novel evidence-based microbiology approach consists of three components:

- Use of practical field methods to test the bacterial quality of water;
- Sharing test results with communities and educating them about the relationship between fecal contamination of water and disease;
- Provision of practical HWTS methods, using chlorine or heat, to kill the germs and make the water safe to drink.

One barrier to the adoption of a novel approach is the people's belief system. Chienjo (2013) suggested that through educational training and testing of household water using the PML, and by showing them the dangers of germs on the body, the villagers are changing their drinking habits in relation to water treatment in Lower Nyakach.

Nature of the Study

The WHO advocates a risk assessment approach for water quality analyses. Risk analysis combines the results of *E. coli* counts with a sanitary inspection (WHO, 2005). The sanitary inspection consists of a visual analysis of factors affecting water quality and needs no equipment. Ultimately, the value of water quality interventions in preventing diarrheal disease depends not only on effectiveness, but also on their sustainability, acceptability, affordability, and scalability within a vulnerable population (Sobsey, 2002).

Table 2

Correlation of E. coli Levels with WHO Disease Risk Categories

Level of E. coli	WHO disease risk level[a]	WHO action priority	MSF action[b]
<1 in 100 mL	Very low	None	None
<1 in 10 mL	Low	Low	Consume as is
1-10 in 10 mL	Moderate	Higher	Treat is possible
1-10 in 1 mL	High	Urgent	Must be treated
>10 in 1 mL	Very high	Urgent	Reject or thoroughly treat

Note. [a]WHO/UNICEF: A Toolkit for Monitoring and Evaluating Household Water Treatment and Safe Storage Programmes (2012), Figure A-1, p.62.
[b]Médecins Sans Frontières (1994) Public Health Engineering in Emergency Situations. Médecins Sans Frontières: Paris.

The missing link in risk analysis surveys has been the ability of water quality development programs to monitor and directly test for *E. coli*. An impact evaluation of the FOTO project, using evidence-based microbiology, provided the needed data to assess the effectiveness and sustainability of this program.

Basically, HWTS should be viewed as a stopgap for water treatment as they are intended for people who do not have access to an improved source of drinking water (WHO/UNICEF, 2015). Two HWTS methods were used in this project. The first method was the use of a simple solar Cookit using sunshine to pasteurize water. A wax-based, reusable water pasteurization indicator (WAPI) verified that the pasteurization temperature of 65°C was reached (Safapour & Metcalf, 1999). The second was the commercially available WaterGuard, a 1.2% solution of sodium hypochlorite that comes in a 150 ml bottle. A capful, 3 mL, was used to treat water in a 20 L jerry can. A bottle of WaterGuard will treat 1,000 L of water, sufficient to last most families at least 2 months (Alekal, 2005; R. Metcalf, personal communication, October 18, 2014) with a target free chlorine residual no greater than 2.0 mg/L 1 hour after chlorine addition, and no less than 0.20 mg/L for 24 hours after chlorine addition (Lantange, 2008).

I conducted a cross-sectional study of the 69,000 cohort and quantified the effectiveness of the intervention by

- comparing temporal trends of hospital admission records for diarrhea before and after the introduction of novel water treatment interventions in Lower Nyakach;
- testing the presence and amount of *E.coli* in the household water storage unit and the associated drinking water source for control comparison using the PML as a measure of risk and verification of intervention adoption;
- testing the free chlorine residual in the household water storage unit and the corresponding drinking source water for control comparison to evaluate correct treatment dosage by adopters;
- geo-referencing sample locations for spatial analysis by mapping the results using the Global Information System (GIS);
- conducting the JMP household survey to study participants to determine self-reported drinking water/sanitation habits.

The primary outcome of this evaluation was to determine whether an association exists between the observed decrease in diarrhea morbidity from hospital and clinic records in Lower Nyakach, and the 2012 introduction of the novel evidence-based microbiology method. This strategy included the three “T’s”: “Teach, Test, and Treat”. An educational component followed by evidence testing helped villagers to understand the connection between contaminated water and disease. Following the introductory education the community was shown appropriate treatment technology using solar heat pasteurization and chemical disinfection.

Definitions

Adopter: Study participants who use the evidence-based microbiology approach to treat their drinking water either by chlorine disinfection or heat pasteurization. The adopter’s HWTS unit will be considered to have a low risk of disease as determine by WHO’s level of risk and verified by the PML as having no *E. coli* in the treated water.

Cookit: A panel-style solar cooker made of cardboard and foil shaped to reflect the maximum sunlight onto a dark cooking pot that converts sunlight into thermal (heat) energy. Its simple and elegant design is affordable, effective, and convenient for cooking the family meal and pasteurizing drinking water to the world’s neediest.

Diarrhea: Three or more loose stools in the previous 24 hours.

Fireless cooker: A fireless cooker uses stored heat to keep cooked food hot over a long period of time or to finish cooking. The food is brought to a boil on a traditional stove before it is transferred to the fireless cooker. The cooker is well insulated, keeping the heat in the food and allowing it to continue cooking inside. A simple basket, insulated with local resources such as banana leaves or old clothes, can reduce fuel use by 40%, preserving scarce fuel wood and saving people hours of precious time.

FOTO. Friends of the Old Development Group is a community-based organization in Lower Nyakach, Kenya. FOTO particularly assists elderly grandparents who raise their grandchildren orphaned by AIDS/HIV. FOTO provides education and training in safe water treatment and storage practices. FOTO provides chlorine (AquaGuard) to all 15,000 households. FOTO also provides limited quantities of Safe Water Packages (SWPs), reading glasses, and certified seeds to villagers most in need.

Location: A geographical boundary consisting of at least ten villages. A typical location in Lower Nyakach has a population of approximately 5,000.

Nonadopter: Study participants who do not or incorrectly use the evidence-based microbiology approach to treat their drinking water either by chlorine disinfection or heat pasteurization. The nonadopter's HWTS unit will be considered to have a moderate to very high risk of disease as determine by WHO's level of risk and verified by the PML as having *E. coli* in the treated water.

Participatory Hygiene and Sanitation Transformation (PHAST): An innovative approach positing that change in people's behavior towards sanitation and hygiene will not occur without understanding and believing.

Safe Water Package (SWP): Consists of a Cookit (solar cooker), a black pot, a WAPI, and a ceramic water storage container along with a 150 ml bottle containing a 1.2% solution of sodium hypochlorite (AquaGuard). Also included in the package is an improved cook stove, the Upesi Jiko cooker.

Safe Water System (SWS): A household-based approach for making drinking water safe, developed by the CDC as an interim measure to protect health until piped, treated water becomes an option for the community. The SWS includes disinfection, storage, and education for behavioral change.

Solar Water Pasteurization: Destroys all microorganisms that cause disease from drinking contaminated water by heating the water to 65°C in a solar cooking device.

Village Access Facilitator (VAF): Twelve staff members of FOTO, each assigned to a location consisting of 10 or more villages. The VAFs travel throughout their location, teaching groups, schools, and villagers about safe water practices, water testing, and water pasteurization. VAFs distribute WaterGuard, SWPs, reading glasses, and certified sorghum seeds. They follow up with recipients to ensure that the people served get full benefit from FOTO programs.

WaterGuard: A water disinfectant consisting of a 1.2% chlorine bleach solution. WaterGuard and AquaGuard are manufactured by the SuperSleek company in Nairobi WaterGuard is distributed by Population Services International (PSI), Nairobi, Kenya.

Water Pasteurization Indicator (WAPI): The WAPI is a simple thermometer that indicates when water has reached pasteurization temperature of 65°C and is safe to drink. The WAPI consists of a small polycarbonate tube containing a wax that melts when water is heated to 149°F (65°C), which is well below the boiling point of water (100°C).

Assumptions

Diarrhea, cholera, dysentery, and typhoid are the major waterborne diseases with high prevalence, particularly among children under 5. This is largely attributed to use of unpasteurized water due to high costs of cooking fuel (Gilman & Skillicorn, 1985). Former public health campaigns have taught people to boil potentially contaminated source water to provide a microbiologically safe drinking supply (Alekal, 2005; MMWR, 2010). A study by Rosa and Clasen (2010) indicated that only 4.9% of populations in African countries boil their water. Why villagers do not adhere to this practice maybe two-fold: (a) constraints of time and resources and (b) local belief systems.

Water boiling is often impractical in locations where household water sources are heavily contaminated and poverty levels are high. Deforestation of the landscape has made fuel wood scarce and people (mainly women) must walk farther distances to collect enough wood to cook the family meal. The purchase of fuel wood, charcoal, and cook-stove gas may be cost prohibitive (it takes approximately one kilogram of firewood to boil one liter of water). Yet, as Ciochetti (1984) demonstrated, water must only be heated to water pasteurization temperature of 149°F (65°C) to be free from disease-causing microbes (see **Error! Reference source not found.**).

Table 3

Temperatures Which Kill Disease Microbes Present in Contaminated Water

Microbe	Killed Rapidly
Worms, Giardia, Entamoeba, Cryptosporidium	131°F (55°C)
Escherichia coli, Shigella, Cholera, Typhoid, Rotaviruses, Polioviruses	140°F (60°C)
Hepatitis A Virus	149°F (65°C)

Another barrier to the adoption of water treatment may be the people's belief system. Dinah Chienjo, Executive Director of FOTO, has said,

> The people have since time immemorial believed that water was blessed from the beginning and cannot cause any diseases, but through the education and by showing them the results of the tested waters and telling them the dangers of the germs on the body, they are beginning to change their drinking habits. Looking back, many people agree that the many stomach related diseases they have suffered in the past have been a result of the bad river or pond water they have been drinking. (Chienjo, 2013)

It can be assumed that living in extreme poverty exposes people to multiple risks to health. A strong association exists between poverty and the lack of access to a safe drinking water source (Blakely, Hales, Kieft, Wilson, & Woodward, 2005). Since the majority of participants in this study live in extreme poverty, one may assume that the preconceived beliefs and/or financial barriers that prevent the adoption of a safe water intervention must first be addressed before the technology is embraced. The measure of program sustainability is dependent on the use of the treatment intervention correctly and consistently, thus a people should be first educated to address their fears, misconceptions, and biases before the adoption of a novel strategy.

Scope and Delimitations

The scope of the study is an assessment of household water storage vessels for chlorine residual, the presence and quantity of *E. coli*, and a self-evaluation of water treatment habits as contained in the JMP survey. The effectiveness of the intervention strategy was measured by the comparison of diarrhea morbidity prevalence since the introduction of the novel evidence-based microbiological approach.

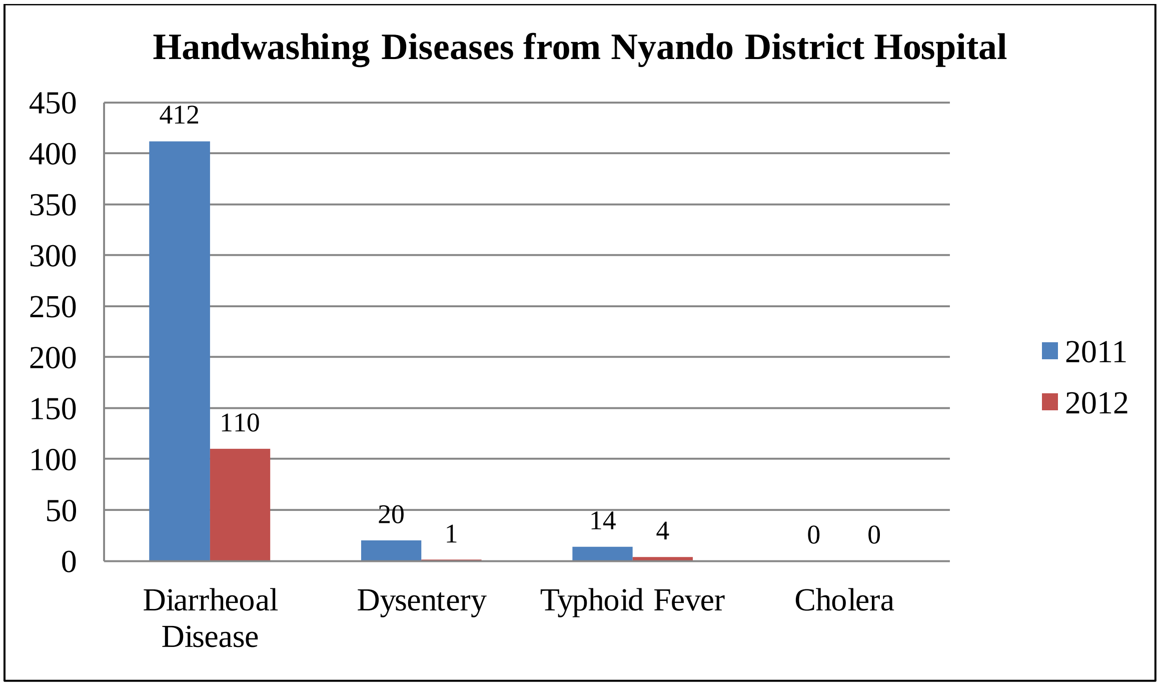


Figure 1. Handwashing diseases from Nyando District Hospital.
WaterGuard Distribution by FOTO, started February 2012, demonstrates an anecdotal correlation with a decrease in diarrheal morbidity. Data courtesy of Nyando District Hospital, Pap Onditi 15 March 2013.

A retrospective time span of 3 years (2009-2012) determined the average prevalence of diarrhea morbidity before the advent of water treatment in Lower Nyakach. The novel strategy to eliminate waterborne disease began with the use of solar water pasteurization education and the introduction of chlorination in February 2012. This study included a 3-year impact evaluation (2012-2015), as a 3-week data collection survey was conducted in July, 2017. Over 350 households from the 9,495 study cohort were sampled. This impact evaluation was chosen as the best way to assess the effectiveness of the novel evidence-based microbiological intervention to improve the microbial quality of the drinking water and to prevent waterborne infectious disease.

The project target area of Nyakach comprises two divisions, namely Upper and Lower Nyakach in Nyando District in Nyanza Province in the western Kenya region. The socioeconomic statistics show that Nyando District has a total of 68,371 households with an average household size of 4.4 persons; extreme poverty is at 68.9%, and 90% of households use firewood and charcoal as a major source of fuel for cooking (Sunny Solutions, 2008).

This study focused on the 182.6 km^2 Lower Nyakach region. The study area has a population density of 299 persons per km^2, with approximately 15,000 households, totaling 69,000 people. Three cluster areas surrounding the hospital and health facilities, comprising 9,495 households, were included in the study cohort. I excluded the Upper Nyakach from this study due to the limiting factor of the community base organization's area of operation.

Chlorine disinfection for household systems was distributed by FOTO to every household in Lower Nyakach. The SWP distribution is more limited due to cost, thus the most vulnerable of the population are given priority. Limited amounts of Safe Water Packages are provided to FOTO monthly and are further distributed to the location chief and village elder who make the determination who among their village are most in need.

The MDG 7C relies on a people's access to an improved water source as a proxy indicator for waterborne disease risk (WHO, 2010). Given that the types of source water available may differ from country to country, the source water diversity of the Lower

Nyakach area appears to be characteristic of many communities in many countries. Unimproved sources such as ponds, streams, rivers, open hand-dug wells, and improved sources such as boreholes and covered wells will be tested for microbial safety. Using the WHO guidelines of *E. coli* risk (see Table 2) and the PML testing of the sources to establish the risk, a general relationship between source water qualities from this study may be adapted to other regions in Sub-Saharan Africa.

The cohort study size of 9,495 households well established a solid correlation to the general population of 69,000 people to determine diarrhea prevalence, intervention adoption, and effectiveness. A random sample size of 300-350 households was considered adequate to represent the whole.

Limitations

This study is delimited to treating water for microbial contamination with solar pasteurization, chlorine disinfection, or by a combination of both methods. Although removal of pathogens by filtration, absorption, or sedimentation is very promising, these will not be addressed in this study. A combination of flocculation with disinfection will also not be addressed. Thus, comparisons to outside randomized controlled trials will be restricted to intervention treatments by chemical disinfection and water pasteurization.

There is a challenge in assessing the causation of diarrhea morbidity, whether from a waterborne or non-waterborne source (Levy, Nelson, Hubbard, & Eisenberg, 2012). Determining drinking water sources other than the participant’s home water storage system is another confounder that may not be fully answered by the JMP survey. Household interventions require vigilance and diligence on the part of householders to treat their source water correctly and consistently, avoid recontamination, and refrain from drinking from untreated sources. Each step affords an opportunity for noncompliance, thus reducing the intervention's effectiveness (Clasen et al., 2007).

In the Nyanza Province, the prevalence of anemia in children under 3 was shown in a cross-sectional study to be 71-76% (Harris et al., 2012). The Demographic and Health Survey (2008-2009) indicated that 24% of children under 5 years had symptoms of malaria, and 17% had diarrhea 2 weeks previously. Anemia, malaria, and diarrhea can be prevented by iron-fortified food, mosquito bed nets, and household chlorination respectively (Harris et al., 2012).

The Safe Water and Aids Project (SWAP) sponsored by the CDC in western Kenya uses a social marketing approach to sell and distribute health products, such as WaterGuard, through local women's business groups known as SWAP vendors. A multiple micro-nutrient powder (Sprinkles) to prevent "low blood," the local name for anemia, along with WaterGuard, advertised to make water safe, are two products that demonstrate the dichotomy of uneven and inequitable distribution of socially marketed products. WaterGuard sells for 20-25 KSh, whereas Sprinkles sell for 1-2 KSh. The social marketing approach, designed with an educational facet to motivate healthy behavior combined with the provision of attractively packaged, affordable products and services to low-income families, has the limitation of requiring individuals or families to have at least some disposable income. Most families purchase the lower cost Sprinkles, but only 23% of families in the lower SES quintiles demonstrated owning WaterGuard in a first-year follow-up survey (Harris, 2012; SWAP, 2012).

The FOTO project uses an evidenced-based microbiology approach and supplies each of the approximate 14,000 families in the study cohort with AquaGuard at no charge. Comparing the neighboring programs from the Nyanza District (the FOTO project in Lower Nyakach and the SWAP project in the Western Province) required adjustments in chlorine usage among study participants.

Significance

Water quality monitoring is often the missing factor in developmental programs to improve access to safe drinking water. Basic standardized tests using a multiple tube fermentation or membrane filtration method require specialized equipment and training and are not easily adapted to field testing (Parker, 2012). In addition, the linkage between water quality and disease is commonly not appreciated at the community or household level (Alekal, 2005, Chienjo, 2014).

The PML, developed by Metcalf (2010), has been field tested by UN-Habitat in Kenya, Tanzania, Uganda, Ethiopia, and Rwanda. In Latin America, the PML has been field tested in Costa Rica, Nicaragua, El Salvador, Guatemala, and Honduras by Habitat for Humanity. The evidence-based microbiology method consists of a comprehensive teaching component using the PML and the UN-Habitat booklet: "A practical method for rapid assessment of the bacterial quality of water" (2010). The teaching component demystifies microbiology at the community level and leads to an understanding of the relationship between contaminated water and disease. Study outcomes from the FOTO experience demonstrate that the ability of communities to understand this relationship has already translated into changes in behavior, including an understanding that their contaminated drinking water sources must be treated every time, using either 1.2% bleach or pasteurization with a simple solar cooker, heating water to 65^{o}C (D. Chienjo, personal communication, July 7, 2015).

Given that close to one billion people face this same challenge globally, the introduction of a readily available water quality testing and monitoring method that is simple and easy to use may significantly contribute to a decrease in the incidence of water-related illness by making knowledge and information more accessible.

Summary

In 2000, the United Nations established MDG 7C, which aimed to reduce by one-half the proportion of the world's population without access to safe drinking water and sanitation by 2015. Because MDG 7C does not strive for universal access to drinking water, achievement of MDG 7C would still leave 800 million people without access to safe drinking water.

Lower Nyakach, near Lake Victoria in western Kenya, has a population of 69,000 with over 60% living in extreme poverty. The main sources of water are highly contaminated, resulting in a high incidence of waterborne disease in Lower Nyakach. This very poor area was not among the beneficiaries of improved water sources in MDG 7C.

FOTO is a community-based organization working in the 12 locations of Lower Nyakach. FOTO has a special focus on helping economically disempowered senior citizens who take care of grandchildren orphaned by HIV/AIDS. The top priority of FOTO is to eliminate waterborne disease in Lower Nyakach. To accomplish this, FOTO has taken a three-pronged approach of (a) using practical field methods involving community members to assess the bacterial quality of drinking water sources; (b) educating communities, including schools, about the relationship between fecal contamination of water and disease using evidence-based bacterial tests; and (c) introducing readily-available HWTS methods.

The strategy of involving communities in evidence-based microbiology testing of water water sources and providing inexpensive treatment options to impoverished families has reduced the burden of waterborne disease in Lower Nyakach. Since the initial introduction of the intervention in February 2012 to 4,800 families, FOTO has seen a 73% reduction in the incidence of diarrhea (see

Figure 1. Pap Onditi Hospital diarrhea trend
Courtesy, Nyando District Hospital, 2013

).

This study needed an outcome evaluation to determine the efficacy and sustainability of the project. The program could be replicated throughout Kenya and in other countries with extreme poverty to reduce the disease burden of approximately 800 million people not affected by MDG 7C. In Chapter 2, I will explore current research in detail and identify gaps that this study addressed.

Table 4

Study Variables and Metrics

Variable type	Variable name	Measurement (Scale)	Values	Reference
Dependent	Change in diarrhea morbidity	Quantitative (Ratio/Interval)	Rate/No. of cases	District Hospital Pap Onditi
Independent	WHO risk of disease	Categorical	Low – Very High	WHO Risk Table
Supporting Independent Variable	Possession of safe water storage unit	Categorical	Yes/No	JMP Survey Question 5C, 5D
Supporting Independent Variable	Method of treatment	Categorical	Type	JMP Survey Question 4, 5
Supporting Independent Variable	Frequency of method of treatment	Categorical	1 = Continually 2 = Less than every time	JMP Survey Question 5B
Other Independent Variables	Time since exposed to novel training	Quantitative (Ratio/Interval)	Months	JMP Survey Question 5A FOTO Records
Other Independent Variables	Source of water	Categorical	Type	JMP Survey Question 1
Other Independent Variables	Type of safe water storage vessel	Categorical	Type	JMP Survey Question 5C, 5D
Other Independent Variables	Self-reported assessment of drinking water safety	Categorical	Yes/No/Don’t know	JMP Survey Question 5F

Chapter 2: Literature Review

Introduction

In this chapter, I will discuss relevant literature and theoretical foundations that introduce a novel strategy to reduce waterborne disease into communities without improved water sources for very little cost. I will include how the FOTO community-based organization of Lower Nyakach empowers their people with skills and knowledge to evaluate their drinking water sources using a rapid and easy-to-use test for reliable indicators of fecal contamination at the community and household level and appropriate treatment methods to produce a safe drinking water. The two main HWTS methods for treating water at the household level, solar water pasteurization using free energy from the sun (Ciochetti & Metcalf, 1984; Safapour & Metcalf, 1999) and inexpensive chlorine dosing of source water collections, will be discussed as the interventions of choice (Alekal, 2005; Clasen et al., 2006; Lantagne, 2008). The Safe Water Package (SWP), supplied by FOTO, provides the necessary resources to treat household water and decrease the incidence of contracting a waterborne disease.

This chapter will also include a review of the history of water testing and the difficulties associated with the thermotolerant coliform analysis and the advent of a PML that is appropriate for use in rural areas of developing countries (Metcalf & Stordal, 2010). I will also describe the literature search strategy employed for this study and explain the theoretical foundation that grounds the study to the hypothesis and research questions. An in-depth literature review relating the key variables will be followed by a summary of the major literature themes and how this study might satisfy a knowledge gap in the literature.

The Novel Strategy: FOTO's Evidence-Based Microbiology Program

FOTO is a community-based organization working in the 12 locations of Lower Nyakach. FOTO has a special focus on helping economically disempowered senior citizens who take care of grandchildren orphaned by HIV/AIDS. The top priority of FOTO is to eliminate waterborne disease in Lower Nyakach.

PHAST theory suggests that the administration of the health program be designed and conducted by capable stakeholders from the (Simpson-Hebert et al., 2000). FOTO empowers its people by including them from design conception to project completion. FOTO's three-pronged message to teach-test-treat is introduced into the community with a workshop that includes a teaching component to demystify microbiology. Results provide a disease risk assessment of water sources that correlate with WHO's Guidelines for Drinking Water Quality (WHO/UNICEF, 2015).

Safe Water Package

The SWP and chlorine distribution that FOTO supplies to families provides all the necessary tools to produce hygienically safe water: a solar cooker, a black pot, a WAPI to verify when pasteurization temperatures are reached, and a ceramic water storage container with a narrow opening and a tap spigot, along with a 150-mL bottle containing a 1.2% solution of sodium hypochlorite (AquaGuard). Trained FOTO staff members are also supplied with the novel PML to analyze local drinking water using evidence-based microbiology methods that can be quickly understood and easily used in rural settings. A unique aspect of using the PML is that it can demystify science and microbiology, as correct use of the PML does not require extensive education or scientific training.

History of Water Testing

The history of water testing began shortly after 1876, when Robert Koch developed methods and procedures that led to the isolation of bacteria. Koch demonstrated that the waterborne diseases of cholera, typhoid fever, and bacterial dysentery were caused by specific bacteria associated with the human and animal gut. Scientists recognized the association between fecal contamination and disease and searched for a universal indicator to determine water potability.

The bacterium *E. coli* was found to be the best indicator of fecal pollution but until recently, there was no specific test for *E. coli*. Substitute tests were adopted; first for the total coliform group of bacteria followed by the fecal coliform subgroup and later re-named the thermotolerant coliform bacteria (TtC) in an attempt to be more specific in separating *E. coli* from environmental coliforms that grow on plants and in soil. Because some environmental coliform bacteria can produce false positive results for *E. coli*, the TtC test was not an adequate substitute test for *E. coli*. (Allen et al., 2010; Doyle & Erickson, 2006; Standridge, 2008).

The Problem of Testing

WHO regards the TtC test as a less reliable but acceptable index of fecal pollution when specific testing for *E. coli* is not performed (WHO, 2008). WHO and UNICEF have developed the Rapid Assessment of Drinking Water Quality survey method to evaluate the relationship between improved sources and drinking water quality. The microbiological parameters used for both household and source water levels include TtC, fecal streptococci, and free and total chlorine residual. Bain et al. (2011), assessing the 2004-2005 Rapid Assessment of Drinking Water Quality project using TtC, concluded that the MDG 7C criterion of source water safety was substantially overestimated and recommended monitoring for both source and drinking water by access and safety.

Testing for TtC requires trained personnel, high precision incubators to maintain a temperature of 44^{o}C (Europe, Africa) or 44.5^{o}C (USA) within 0.2^{o}C, and an autoclave for preparing media in bottles/tubes and for disinfecting used samples (Metcalf, 2013). In essence, a well-equipped lab is required, which is rare in developing countries. Data collection for microbiological water quality is limited by the availability of laboratory facilities that can perform traditional monitoring tests and by the cost and time constraints involved in transporting samples (Parker, 2011).

Where field testing kits are available, such as Oxfam's Del Agua unit, Wagtech Potatest, or the ELE Paqualab, they are expensive, bulky, cumbersome, and they test for TtC, not *E. coli* (Parker, 2011). They can be transported by truck or car, but not by motorbike or bicycle. Not only do they require extensive media preparation and in-field disinfection supplies, they also require electricity or battery power to run the incubator, which is not available in most rural areas of Africa (Parker, 2011).

The Portable Microbiology Laboratory

The breakthrough in specific testing for *E.coli* in foods and water came in the late 1980s. The seminal work by Edberg et al. (1988) provided grounding for this study to introduce a novel approach for eliminating waterborne disease in the developing world.

The United Nations Human Settlements Programme for UN Habitat has developed a field-based guide, *A Practical Method for Rapid Assessment of the Bacterial Quality of Water*, that can be performed in the field without the need for electricity, incubators, or laboratory facilities (Metcalf & Stordal, 2010). A simple and effective PML, developed by Metcalf (2010), enables water testing at the community level in developing countries to determine disease risk.

The PML contains the most widely used tests in the water and food industries for the target indicator organism, *E. coli*, because the tests contain the substrate for the beta-glucoronidase enzyme that is produced by *E. coli*, but not by environmental coliform bacteria (R. Metcalf, personal communication, May 24, 2014). The PML allows for effective field work utilizing the easy-to-perform test specific for *E. coli*, without the need of autoclaves, incubators, electricity and extensive training in laboratory science.

Literature Search Strategy

The primary search engines I used in conducting this literature review were CINAHL, MEDLINE, and PubMed, accessed through the Walden University's library page. I also consulted Google Scholar for preliminary searches on a new topic or keyword. Many of the articles found through this search engine could also be obtained on the Walden library page.

The five main categories of literature review relating to this study are (a) treatment methods to prevent waterborne disease appropriate for Lower Nyakach; (b) monitoring of key water quality indicators; (c) testing source and treated water on community and household levels; (d) the FOTO project's use of evidence-based microbiology education and evaluation; and (e) assessment through coverage, performance, and adoption of the novel intervention.

For the treatment category, keyword searches included *home water treatment and safe storage, safe water storage, point-of-use chlorination, solar pasteurization, solar disinfection, waterborne disease treatment, diarrhea,* and *diarrhea prevalence.* Seminal literature for the history and determination of appropriate water treatment interventions for the Nyanza province of Kenya by Alekal (2005), proved to be an invaluable source to focus my literature search. “Solar Pasteurization of Naturally Contaminated Water” by Ciochetti and Metcalf (1984) was the key article to influence the paradigm shift in heat treatment. Health campaigns still call for the boiling of water, whereas Ciochetti proved water need only reach 65^{o}C using free sun energy to inactivate all pathogens of disease thus saving precious fuels and firewood. Studies by Levy et al (2012) and Lantagne (2010) were lead articles for chlorination interventions. Many articles by Quick and colleagues demonstrated a major approach to prevent diarrhea using the SWS, which was developed by the CDC and PAHO. The SWS is a simple, inexpensive method of purifying water at the household level using 1.2% bleach solution, a safe water storage unit, and behavior change communication.

For the monitoring category, keywords searches included *proxy indicators of water quality* and *unimproved/improved water sources.* The WHO/UNICEF JMP for Water Supply and Sanitation was invaluable in explaining the scope, the gaps, and the needs in monitoring water quality at the community level. Doyle and Erickson (2006) represented the literature defending the shift from monitoring archaic fecal coliform

(TtC) testing to modern *E.coli* target tests as the more reliable indicators of recent fecal pollution in drinking water.

For the testing component, valuable keywords were “water quality testing” “rapid detection methods”. The paradigm shift in this concept was aided by Metcalf and Stordal (2010) in using evidence-based microbiology to determine levels of water safety risk. The seminal work by Edberg (2000) set the foundation for testing *E. coli* as the best indicator of fecal contamination in water along with WHO Guidelines for Drinking Water Quality (2011).

For the education and evaluation component of the FOTO project, keyword searches included “water hygiene education” and “water and sanitation hygiene”. The PHAST theory as explained by Simpson-Hebert et al. (2000), helped to gain a better perspective of behavioral change concepts that have permeated the Nyanza province and others areas throughout Kenya and Africa. The WHO HWTS Manual provided excellent insights to the challenges needed in assessing impact outcomes.

To aid in study design and assessment, keywords used were *behavior change models, water hygiene theory, waterborne illness quantitative, and adoption of water treatment.*

Mentor articles used to model this study design were by Fiebelkorn et al. (2012) and Levy et al. (2012) on the household effectiveness of point-of-use water treatment (HWTS) and cross-sectional designs to address diarrheal disease in the developing world.

The vetted demographic and health survey (DHS) by the WHO/UNICEF JMP provided the core set of questions to assess the type of source water, treatment habits of household drinking water, sanitation facilities and disposal of children's feces (WHO/UNICEF, 2006). Articles were only selected in full document format and only if they were published since 2009, with some exceptions for older material that was pertinent and seminal to this topic.

Theoretical Foundation

PHAST is a theoretical design to promote hygiene behaviors and community management using participatory techniques. The basis of the approach is that lasting social change in people's behavior of the adoption of a health intervention will not occur without their understanding and believing.

The PHAST is an adaption of the Self-esteem, Associated strengths, Resourcefulness, Action-planning, and Responsibility (SARAR) methodology of participatory learning developed in the early 1970s by Srinivasan and colleagues. PHAST is a joint project of WHO and the UNDP/World Bank Water and Sanitation Program. The PHAST approach was field tested in rural and urban areas of four African countries: Botswana, Kenya, Uganda, and Zimbabwe.

Some communities and families simply do not have the resources to put their hygiene beliefs into action. In a cross-sectional survey on equity of access to water treatment by Freeman et al. (2009), persons in the upper SES quintiles tended to purchase and use chlorine, whereas barriers to product penetration remained among the very poor and less educated. For example in areas of the Nyanza province in Kenya, many drinking water sources have high levels of turbidity. A product known as PUR, developed by Procter & Gamble and distributed by PSI, has been shown to be an effective water treatment method to remove turbidity and kill germs (Garrett et al., 2008). The product costs $0.01 to treat one liter (1¢/L) compared to a bleach product that can treat 58 liters for the same price, but without the ability to remove the turbidity. In an attempt to determine the use of water chlorination products at the household level in rural Kenya, DuBois et al. (2010) found inconsistent use of the flocculent-disinfectant PUR, and a return to the sodium hypochlorite solution of which community members were probably more familiar.

SWAP and FOTO utilize community participatory hygiene activities but their philosophies' diverge at the dissemination of the intervention. SWAP supposes disposable (discretionary) income among the study population and demonstrates good success with the upper economic quintiles of the population. FOTO targets the extreme poverty and provides chlorine treatment to every household free of charge. SWAP basis sanitation adoption on the presence of chlorine residual in HWTS, whereas FOTO includes evidence-based microbiology results of *E. coli* concentrations using the PML to verify the safety risk.

As applied to this study, I will use PHAST theory to explain the adoption of evidence-based microbiology verification in a community-based water hygiene project. I will demonstrate whether study participants adopt and continually use HWTS interventions because of their belief and understanding that germs of the body can cause stomach disease, and that the simple, low cost point-of-use disinfection and/or pasteurization methods can alleviate the symptoms of waterborne infectious disease.

Literature Review Related to Key Variables and/or Concepts

The key independent variable, the measurement of WHO risk of disease (WHO/UNICEF, 2012) by using the novel evidence-based microbiology approach, consists of verifiable field testing of *E.coli* as proposed by Metcalf and Stordal (2010). The practical PML, developed by Metcalf (2010), has been field tested by UN-Habitat in Kenya, Tanzania, Uganda, Ethiopia, and Rwanda. In Latin America, the PML has been field tested in Costa Rica, Nicaragua, El Salvador, Guatemala, and Honduras by Habitat for Humanity (Metcalf & Stordahl, 2010).

Controversy about using the PML centers on the standard use of 100 mL of sample (WHO/UNICEF, 2013). The United States and European countries have disinfected their water supplies for over a century and thus require 100mL of sample aliquot that is sensitive enough to ensure a 'very low risk' of disease result (see Table 2).

In assessing levels of risk due to the presence of *E.coli* in drinking water, WHO guidelines require testing a 100mL sample within 30 hours using a multiple tube fermentation or membrane filter technology (WHO/UNICEF, 2012). Metcalf foregoes the very low risk category and adopts a 10mL substitution test that is sensitive enough to give a result to determine a 'low risk' of contamination and a 1mL aliquot to determine 'high and very high risk' levels. The 10 and 1 mL aliquots allow for body incubation of the sample in the field bypassing the need of transporting the sample to a regional laboratory within 30 hours for testing and incubation.

In determining the merits of applying a temperate zone test to a tropical area, UNICEF supports an interim approach for a developing country's capability to reach water quality standards:

> WHO guideline values should not be interpreted as mandatory universal drinking water standards. Rather, they should be used to develop risk management strategies in the context of local or national environmental, social, economic and cultural conditions. This approach should lead to standards that are realistic and enforceable in a given setting, to ensure the greatest overall benefit to public health… It would be inappropriate to set such stringent drinking water standards that regulatory agencies lack the funding or infrastructure to enforce them. This would result either in too many water sources being closed and insufficient access to water, or widespread flouting of the regulation. (UNICEF Handbook on Drinking Water Quality, 2008, p. 6).

Summary and Conclusions

Achievement of the MDG 7C still left 800 million people without improved water sources as is found in Lower Nyakach, Kenya. Water quality monitoring is often a missing factor in development programs due to limited availability of laboratory facilities and microbiological expertise (Brown & Clasen, 2012; Metcalf, 2013; Onda et al., 2012; WHO, 2014).

A unique strategy to eliminate waterborne disease in Lower Nyakach was developed by a community-based organization, the Friends of the Old (FOTO). This strategy is introduced into the community with a workshop that includes a teaching component that demystifies microbiology (Metcalf & Stordal, 2010). Results provide a disease risk assessment of water sources that correlate with the World Health Organization's Guidelines for Drinking Water Quality (WHO/UNICEF, 2012).

Up until the 1980s, the thermotolerant coliform (TtC) test was the best available to assess fecal pollution in water. The introduction of beta-glucoronidase tests for *E.coli* rendered the TtC test obsolete (Doyle & Erickson, 2006; Allen, 2010).There is controversy whether interim standards of WHO's Guidelines should be adopted allowing for an intermediate target of <10 E. coli/100mL (WHO, 2013). WHO and UNICEF literature contain statements that water quality standards should be determined by individual countries depending on their resources and capabilities (WHO/UNICEF, 2010b).

The literature search of why people will adopt a novel approach to treat their water supported the PHAST theory that 'seeing is believing' through understanding. Water testing, using the PML, educates the community that drinking water sources are contaminated and must always be treated. Testing replaced myths about water being safe to drink and demonstrates that proper chlorine dose (Levy et al., 2012) or solar heating to 65^{o}C (Ciochetti & Metcalf, 1984) can make the water safe from pathogenic organisms that cause diarrhea, cholera, dysentery, and typhoid.

Of the multiple barriers to acceptance of household treatment of water, product price subsidies targeted to the poor coupled with community motivation may lead to significant adoption of hygienic practices (Guiteras et al., 2015; Onjala et al., 2014). The use of evidence-based microbiology at the community level in developing countries may empower communities with the knowledge and skills to evaluate their drinking water sources and to evaluate available household treatment methods.

Chapter 3: Research Method

Introduction

The design and rationale for conducting this study is discussed in this chapter, including the research questions, data collection methods, methodology, discussion and justification of sample size, potential threats to validity, and possible ethical issues that may arise. A summation of the methodology is submitted for final review and approval by the dissertation committee.

Research Design and Rationale

I chose a cross-sectional design for this study. Markovitz et al. (2012) reported that a cross-sectional design is preferable for diarrheal surveillance in study areas of limited resources. Household risk factor estimates produced by temporal/longitudinal studies demonstrated more variability than the spatial/cross-sectional approach, which yielded more representative and consistent evaluations of disease risk factors across large geographical areas (Markovitz et al., 2012).

The purpose of this survey design is to generalize the drinking water habits of the population from a sample to determine if a reduction in waterborne disease morbidity has occurred since the introduction of a novel approach to reduce diarrhea. The advantages of using a survey in this rural area of Kenya is the rapid turnaround in data collection and the good fit this design has to the Community-based Organization (CBO) structure.

Survey interviews and data collection were conducted by trained Data Survey Specialists (DSS) from the FOTO organization using the vetted JMP/UNICEF demographic survey. The additional novel entity to the survey, to determine the WHO risk level of disease, will be the collection and simultaneous testing of raw and treated water for the presence and concentration of *E. coli* contamination and chlorine residual from study participants' safe water storage containers.

The dependent variable for this study is the change in diarrhea morbidity from reported case admissions from the Pap Onditi District Hospital, Katito Health clinic, and Kibogo dispensary records, 3 years before and 3 years after introduction of the evidence-based microbiology novel strategy. To establish the dependent variable, a temporal/longitudinal survey was used to determine disease trends.

The main independent variable is the WHO level of risk for contracting a waterborne infectious disease (WHO/UNICEF, 2012). The measurement of *E. coli* in surface source water and in HWTS units utilizing PML may verify the effectiveness and continuity of use of the intervention. From this data, it was postulated that an association between the decrease in diarrhea morbidity observed from the district hospital records and *E.coli* concentrations in household safe water units were drawn.

A contributing independent variable is the exposure of the head of household to the educational portion of the intervention, namely, the evidence-based microbiology method utilizing the PML which determined the level of intervention adoption among the study participants. Covariate variables include testing microbiological water quality of on-site household safe water storage vessels for free chlorine residual. Additional independent variables evaluated were the study participants' possession of a SWS storage vessel, the method of treatment used, and the frequency use of the treatment method.

This cross-sectional study using the vetted JMP household survey verified by evidence-based microbiology using the PML, indirectly assessed the health benefits of a HWTS intervention by measuring three general conditions; coverage, performance, and adoption. By testing the HWTS for free chlorine residual and *E. coli* risk concentrations, an indirect assessment on the correct and consistent use of the interventions was used to measure the adoption level of the intervention by the target population.

The study area of 186 km^2 is rural and the predominant mode of travel for survey interview is on foot or bicycle. Seasonal and time constraints to conduct data collection are limited before and after the two rainy seasons. It took three weeks for 12 Data Collection and Survey Specialists conducting two interviews per day to collect the data.

As of June 2015, all of the 68,371 participants in the 12 locations of this study population have been exposed to one or both of the treatment interventions. The resource constraints of the CBO’s ability to expand to other villages to conduct a direct impact assessment on diarrhea morbidity is limited at this time, thus a cross-sectional design using random sampling for an indirect impact assessment of easier to measure intermediate outcomes is optimal (WHO, 2013).

The WHO/UNICEF JMP for Water Supply and Sanitation focuses on monitoring “improved drinking-water sources” rather than on “safe drinking water” because resources do not allow for large scale monitoring of water quality (WHO/UNICEF, 2010a).

Assessing water quality treatment interventions without evidence-based microbiology has been the norm for most intervention studies due to lack of an inexpensive and simple field test for the target organism. Many studies extrapolate chlorine residual tests from household HWTS as evidence for intervention usage and outcome safety of household drinking water (Clasen et al., 2006; Lantange, 2008; Levy et al., 2012), but do not necessarily have success in behavioral change in drinking water treatment habits.

The evidence-based microbiology approach utilizing the novel PML contains a teaching component that demystifies microbiology at the community level and leads to an understanding of the relationship between fecal contamination of source water and household diarrheal disease. Making this connection leads to an understanding that drinking water sources must be treated every time using either 1.2% bleach solution or by heat pasteurization with a simple solar cooker. These two interventions used are economically feasible for this extreme poverty laden area. Given that close to 1 billion people face this same challenge globally, assessing the adoption of a readily available water quality and monitoring method that is simple and easy to use, may significantly contribute to a decrease in diarrhea morbidity (Safapour & Metcalf, 1999).

Methodology

Population

The 186 square kilometer (km^2) study area in Lower Nyakach, near Lake Victoria in western Kenya, contains approximately 180 small villages divided into 12 locations. The area has a population of 69,000 with over 60% living in absolute poverty (Solar Cookers International, 2008). Members of the Luo tribe represent the dominant ethnic population with subsistence farming and migrant labor as major occupations (Suchdev et al., 2010).

Sampling and Sampling Procedures

Prior to data collection, a spatial GIS mapping of Lower Nyakach, commissioned by Bright Water Foundation (BWF) and conducted by FOTO, was used to determine the sampling pool of participants to conduct sampling for the cross-sectional design. It was determined, from the GIS map (see Appendix G), that the villages that feed the Pap Onditi County Hospital, the Katito Health Clinic, and the Kibogo Dispensary would be used to represent the area of Lower Nyakach because households from these areas would give a better cross sectional representation of diarrhea trends from the communities. I selected a random sampling by location of the estimated 9,495 households (8,124 using chlorination only; 1,371 using solar pasteurization and/or chlorine) in the study area to ensure that villages throughout the study region were represented proportionally. The data collection took place during a 3-week time frame between the rainy seasons of 2016.

A power analysis using SPSS-16 and an alpha level and effect size of 0.05 and 0.80 respectively was used to determine the sample size needed for the study. Due to financial and resource constraints, I chose to sample between 300 and 350 households, a far greater number than is needed for power level compliance.

Procedures for Recruitment, Participation, and Data Collection

Due to FOTO’s good rapport among the general population, location chiefs and village elders, the total population size in the three study areas of 9,495 families were included. The selection of study households invited to this study was by computerized random sampling. The criteria to select participants were from those villagers who receive the chlorine disinfectant, AquaGuard, and/or have received a SWP including a solar Cookit through IWHA and FOTO.

Household information included type of HWTS unit, source water, and sanitation facility. Village maps with GPS coordinates of all households and important landmarks including source water sites were documented. The households were assigned a unique geocode from which a randomized sample was obtained.

The FOTO Data Survey Specialist (DSS), who conducted the field household survey provided a consent form written in English and Luo explaining the questionnaire procedures and the random sampling of the HWST unit (Appendix F). Participants were asked to give written consent before the interview process took place (Appendix C). Before any villager was approached, buy in and consent to operate in the village was obtained from the village chief and elder

The trained DSS collected drinking water samples from the household safe water storage unit after the household survey was conducted. The sample was aseptically collected in a sterile WhirlPak bag (Nasco, Fort Atkinson, WI; bags pre-packed with sodium thiosulfate tablets will be used for chlorine-treated water). Free chlorine was immediately analyzed by the DSS using Water Works 2 Water Quality Test Strips (Industrial Test Systems, Rock Hill, SC). Sample collection instructions may be found in the Appendix F.

Source water and HWST post treatment was sampled to determine the adoption and effectiveness of the treatment program. All samples were collected, tested, incubated, and recorded by trained FOTO personnel. These data collectors also administered the vetted JMP household survey to determine sanitation and water treatment habits of household members.

The chlorine residual results were immediately reported on the data sheet and the microbiology results of the PML were recorded within 24 hours after incubation at body temperature (Appendix B). The DSSs returned the questionnaire, data report sheet, used chlorine test strips, incubated and recorded Colilert tubes and corresponding Petrifilms for both the household HWST unit and source water sample to the project coordinator. Microbiological test samples were photo documented, processed, decontaminated by solar pasteurization and disposed of according to good laboratory practices by the supervising researcher. The recorded data were electronically transferred to the lead researcher for further analysis.

A key aspect in the treatment of human subjects is to provide informed consent, which is an agreement obtained from each participant stating that nothing may be done to the subject (physically, emotionally, or mentally) without them first being told what is happening, why it is happening, and having them fully agree to participate (Emporia State University, 2014).

The DSS obtained written and signed consent from each study participant after explaining that participation was completely voluntary and could be withdrawn at any time (Creswell, 2013). The informed consent document contains the following element: (a) A statement of the study that describes its purpose, expectations, and duration; (b) A description of any possible risks or harmful elements of the study; (c) A description of the possible benefits for participants and their communities; (d) A statement that discusses how data will be kept confidential; (e) A statement with information on who is running the study, along with contact information for the researcher(s) and the university; and (f) A statement that participation is voluntary and that participants can refuse to answer any questions or participate in any portion of the study; they were able to withdraw their participation at any time (Emporia State University, 2014).

Also included in the informed consent document was contact information for myself and the University, as well as information about the IRB approved study, including the IRB approval number. Follow-up interviews are not anticipated, but if needed, will be conducted by the FOTO project coordinator, and forwarded to the lead researcher via email. All study participants received a thank you gratuity conducive to the local customs and traditions of the region. Results of the study data have been shared with the FOTO Staff and further disseminated to the study participants at the village chief Barazas meetings.

Operationalization

The dependent variable, the change in diarrhea morbidity of case admissions from the district hospital in Pap Onditi, Katito Health Center, and Kibogo Dispensary in Lower Nyakach, Kenya, is a quantitative (ratio/interval) measurement that determined the prevalence rate of diarrhea from the number of observed cases. The number of diarrhea cases in children under 5, from January 2012 before the introduction of the novel strategy to January 2013, decreased by 54%.

The main independent variable, the WHO level of risk as determined by the concentration of *E. coli* in the study participant's drinking water, is a categorical measure with values ranging from low risk to very high risk. A sample that demonstrates the absence of *E.coli* in a 10-mL sample is determined to be low risk. A 1-mL sample that demonstrated between 1-10 colonies of *E. coli* is determined to be of high risk. A 1 mL sample that demonstrates greater than 10 colonies is of very high risk.

A secondary independent variable using FOTO historical records of the number of people exposed to the novel evidence-based microbiological training and treatment of HWST units, known as the FOTO method, is a quantitative (ratio/interval) measurement. Comparing the three year temporal trends post introduction of the novel intervention served to demonstrate the association of a reduction in diarrhea to the increase of awareness and use of the FOTO method.

The free chlorine residual was measured using Water Works 2 Water Quality Test Strips (Industrial Test Systems, Rock Hill, SC). *E. coli* was measured by the PML (Metcalf, 2010). The concentration of the *E. coli* in HWTS units determined the level of risk as established by WHO (see **Error! Reference source not found.**).

Table 4 shows the categorical measurements and values of supporting independent variables that will be gleaned from the JMP survey questions.

Data Analysis Plan

Statistical software employed for this study was SPSS-16 (SPSS Inc., Microsoft, Chicago, IL). Every household in the 9,495 cohort study had an equal chance for participation to determine the coverage, performance, and adoption rate of the evidence-based microbiology approach tool. Evidence of the use of the tool addressed the hypothesis that the observed reduction in diarrhea prevalence in Lower Nyakach was associated with the use of HWTS methods among participants of the FOTO/evidence-based microbiology study.

RQ1. Is there an association between the change in diarrhea morbidity in Lower Nyakach, Kenya, and the novel evidence-based microbiology intervention?

The hypothesis was that diarrhea morbidity would decrease as the number of households exposed to the novel intervention increased. The diarrhea morbidity was measured by the number of cases admitted per month at three nearby health facilities. I used one data point for each year which represents the average over 12 months. The number of households exposed to the intervention was recorded on a monthly basis, with each data point representing the average for that year. The yearly averages accounted for the seasonal weather changes which may have affected water quality (Alekal, 2005).

Three year diarrhea records pre and post introduction of the novel intervention was assessed through univariate analysis of the triennial trends to test this hypothesis. The standard student t-test was first used to establish this comparison. Second, a post-intervention analysis was performed over the three year period following the introduction via linear regression and statistical significance analysis to further examine the correlation between the diarrhea morbidity and the number of households exposed to the intervention.

A small probability (P-value) provided good evidence against the null hypothesis which demonstrated a change in drinking water treatment habits among the population (Gerstman, 2008, p. 181).

RQ2. Is there an association in WHO risk of waterborne disease and the possession of a safe water vessel?

The hypothesis was that the possession of a safe water vessel would be associated with a lower WHO risk level. The possession of a household safe water vessel was recorded on the JMP survey and witnessed by the DSS survey interviewer. The WHO level of risk (see table 2) was determined by using the PML to measure the concentration of *E.coli* in the household's drinking water and also recorded on the JMP survey. To test this hypothesis, a chi square test was used to determine whether or not the possession of a safe water vessel was associated with the WHO level of risk.

RQ3. Is there a difference in WHO risk between solar pasteurization users and chlorine bleach users?

The hypothesis was that there would be no association between households using solar pasteurization versus chlorine bleach and the WHO risk level. For this analysis, study households were put into one of two categories: Those households in possession of the solar pasteurization equipment were deemed "solar pasteurization users." Those in possession of chlorine bleach only were deemed "chlorine bleach users." Verification of chlorine use was demonstrated by the chlorine residual tested by the DSS at time of the interview. To test this hypothesis, a chi square test was used to determine whether or not either method is associated with the WHO level of risk. Those families possessing none of these methods were not included in this data set.

Univariate examination of risk factors.

To establish whether an association existed with the observed decreased in diarrhea trends since the intervention of 2012, the WHO risk factors were be evaluated by applying a univariate logistic regression. The univariate regression was then applied to study the association between the microbiological data and other independent variables (Table 5). Seven independent factors were tested for association.

Risk factors

E. coli concentrations and residual free chlorine were determined at the time of sample collection along with a standardized questionnaire to evaluate possible risks factors associated with the colonization of the target organism. The vetted survey established the participating family's source water, method and frequency of treatment, and type of safe water vessel used for storage. Additional information on the participant's self reporting assessment of drinking water safety and the time (months) since being exposed to the evidence-based microbiological training (FOTO method) established water safety (see Figure 17).

Multivariate examination of risk factors.

Variables that demonstrate significance ($p<0.05$) in the univariate analysis, were entered and reanalyzed by means of multivariate conditional logistic regression models.

Statistical analysis

All statistical calculations were made with SPSS/pc (SPSS Inc, Chicago, IL). Logarithmic transformations were used in statistical analysis to normalize the non normal distributions, and results were presented as geometric means. The results were analyzed by correlation analysis, t test, one-way analysis of variance (ANOVA), and by chi-square test. Odds ratio (OR) and 95% confidence intervals (CI) were calculated to assess categorical risk variables associated with microbial contamination and thereby compared diarrhea trends of disease from the district hospital, health clinic, and dispensary records.

Threats to Validity

Internal threats to draw correct conclusions of evidence-based microbiology associations with a reduction in diarrheal morbidity are addressed in this section. Threats involving the participants (i.e., history, maturation, regression, selection, and mortality) were minimized by using a cross sectional design to collect data in a capsulated period of time (Markovitz et al, 2012). The use of random sampling of the population equally distributed the chances and reduced the bias of selection and regression.

Diffusion of treatment was the greatest internal threat to validity to this study. It was estimated that a three week time frame was be needed to conduct the JMP survey throughout the 186 km^2 study area, since transportation was by foot. Once the survey was started, rumors of the survey contents were difficult to contain as news travels quickly by word-of-mouth from village-to-village (D. Chienjo, J. Abende, F. Ogutu, personal communication, July 9, 2015). To adjust for the reporting bias that occurred by news of the survey preceding the data collection by the DSS, responses to the survey were verified by using evidence-based microbiology to establish adopter status and to minimize misclassification.

External threats to validity were minimized by verification of adopter status using the PML to determine the concentrations of *E. coli* in the HWTS units. The interaction between the history of diarrheal morbidity and the treatment to reduce the effects of the disease were limited to the present time resources of the CBO's ability to replicate this study over time. It is anticipated that this factor will change in the future with outside funding and support services from donor agencies. At present time, the cross sectional design to indirectly assess the impact of HWTS by focusing on the coverage, performance, and adoption of the evidence-based microbiology approach used by FOTO, is the best way to address the external threats (Markovitz et al., 2012).

Ethical Procedures

Ethical considerations for this study include that the data collected through interviews include information on people who live in marginalized areas in developing countries. The ethical considerations of this study focused on protecting the participants; this involved taking measures to keep data anonymous and confidential, and ensuring that the study and its results benefited the participants and their communities (Creswell, 2013). Results were also disseminated to the participants and communities in order to have the participants share in the applied use of the results (Walden University, 2014).

The data collection package for the random selected household was prepared with an encrypted UTM coordinate to ensure privacy to the identity of the homeowner and occupants. The study was explained to the selected participant and consent forms were signed and returned to the FOTO project coordinator. Survey interviews were conducted and physical data collected by the DSS. The survey questionnaires, along with incubated samples, were returned to the coordinator where results were photo-documented and entered into a computer database. These data were emailed to the lead researcher where a unique identifier was attached known only to the lead researcher thus ensuring complete anonymity and privacy of study participants.

Summary

There has been a high incidence of waterborne disease in Lower Nyakach, near Lake Victoria in Kisumu County, Kenya. A gap in securing safe water has been the ability to test water at the community level in developing countries to determine the disease risk of the sample. The community-based organization, FOTO, introduced a novel strategy to reduce diarrhea from drinking water. A 3-year follow-up study was conducted to evaluate the effectiveness and adoption of FOTO's unique strategy to reduce the prevalence of diarrhea using an evidence-based microbiology approach.

The instrument of choice was a cross-sectional design to assess the coverage, performance, and adoption of a community-based goal to reduce the prevalence of diarrhea. A spatial GIS map of Lower Nyakach was used to select the 300-350 participants from the sample pool of households. Selected households were assigned a unique geocode, to ensure privacy, and from which a randomized sample was obtained.

Village participants in the study used two main interventions to treat their drinking water: simple chlorine disinfection and solar pasteurization. Trained data survey specialists conducted the JMP field household survey to determine sanitation and drinking water treatment habits among the participants. Water quality testing was performed by using two commercially-available tests specific for E.coli (Colilert & Petrifilm). HWTS water samples and raw source water were collected to test for concentrations of *E.coli* and free chlorine residual. Independent variables and covariates were analyzed using univariate logistic regression. Those variables demonstrating significance were reanalyzed using multivariate conditional regression and the results were analyzed by correlation analysis.

Threats to internal and external validity were minimized by using a cross sectional design and randomized sampling across the study population. The JMP survey response was verified by evidence-based microbiological tests for *E.coli*, thus reducing reporting bias from the JMP survey. The coverage and performance of the program was determined from the results of this study.

In Chapter 4, the results of the JMP survey supported by evidence-based microbiology verification are analyzed and data statistics were used to answer the hypothesis and research questions.

Chapter 4: Results

Introduction

In this chapter, I will discuss the data findings. Data collection and descriptive demographics of the samples are displayed in graphic and narrative format. I also address and explain discrepancies in data collection from the initial plan. Results of the survey are presented and compared to the observed triennial trends for waterborne disease. The results will be compiled to answer the research questions and hypotheses in summation:

RQ 1: Is there an association between the change in diarrhea morbidity in Lower Nyakach, Kenya, and the novel evidence-based microbiology intervention?

$H_0$1: Diarrhea morbidity will decrease as the number of households exposed to the novel intervention increase.

RQ 2: Is there an association in WHO risk of waterborne disease and the possession of a safe water vessel?

$H_0$2: Possession of a safe water vessel will be associated with a lower WHO risk level.

RQ 3: Is there a difference in WHO risk between solar pasteurization users and chlorine bleach users?

$H_0$3: There will be no observed risk difference between households using solar pasteurization versus chlorine bleach users.

Data Collection

Time Frame

The 186 square kilometer (km^2) study area in Lower Nyakach, near Lake Victoria in western Kenya, contains approximately 180 small villages divided into 12 locations. Previous training for the DHS survey specialists commenced on July 6, 2015 with the lead researcher in country. A refresher course, beginning July 3, 2017, lasted 3 full days consisting of use of the GPS units, understanding and administering the DHS questionnaire, and procedures for conducting the coliform bacteria and chlorine residual testing. Fifteen data collectors, known as enumerators, were evenly assigned to one of the three cluster areas with the goal of administering five questionnaires per day each. The average interview time was 25-30 minutes per respondent.

The data survey started on July 11, 2017 and ended on August 4, 2017. There was a break from the survey exercise because Kenya conducted its National General Election which stalled project activities following country-wide protests and violence due to accusations of a rigged election. Data entry and cleaning resumed in mid-August after safety and security concerns abated. The data were collected and compiled in Kenya and then sent to the lead researcher in California, USA, via email on November 15, 2017 for statistical analysis and review.

Discrepancies in Data Collection

Prior to data collection, a spatial 2015-2016 GIS mapping of Lower Nyakach (Appendix D) was used to determine the sampling pool of participants. The estimated population of Lower Nyakach is 70,000 people consisting of 14,400 households. The GIS survey team identified 9,495 households in three general cluster areas surrounding the Pap Onditi District Hospital, Katito Health Center, and the Kibogo Dispensary. We determined to conduct a random sampling from each cluster consisting of 100 samples each. The DHS survey team expanded the random sample pool from 300 to 385 because of the discovery of extra resources in test materials. During the data collection period, adjustments had to be made for some households previously mapped because their members had relocated to urban centers and some had died. To keep the random sampling intact, I determined beforehand that the enumerator would locate the nearest dwelling to any non-locatable, computer-generated participant to complete the survey. Additionally, outlier samples were generally traced back to the results reported by one DSS enumerator. It was determined that six surveys and results received from the enumerator would be disregarded in order to compensate for rater bias, thus the final sample pool ended as 379.

Recruitment and Response Rate

Of the 379 participating households randomly contacted for this survey, all (100%) responded. After signing a consent form, a household adult family member answered the 30-minute questionnaire (see Appendix A) and allowed the enumerator to collect samples from their home water storage unit for microbiological analysis. Each respondent received a gratuity equivalent to $3 USD, which was a week’s income for most respondents. I felt that the evidence-based verification of the respondent’s answers would compensate for any courtesy bias the gratuity might cause, thus ensuring a high degree of confidence in the collected data.

Descriptive Demographic Characteristics of Population

The demographic and health survey developed by the joint efforts of the WHO and UNICEF was administered by random sampling to study participants living in proximity to the Pap Onditi Hospital, Katito Health Center, and the Kibogo Dispensary in Lower Nyakach, Kenya. Members of the Luo tribe represent the dominant ethnic population of 69,000, with over 60% living in absolute poverty. Migrant labor and subsistence farming make up the major occupations of the region. Christianity is the major religion with over 70 different sects. The majority of households visited were constructed of earthen material.

Main raw drinking water source for households. The main raw sources for drinking water for household members varied from river, rainwater collection, protected dug wells, boreholes, public tap/standpipes, and piped water into yard or into a dwelling (see *Figure 2*). The main sources of water used for cooking and handwashing included the above plus ponds, streams, canals, lakes, unprotected springs and dug wells (see *Figure 3*).

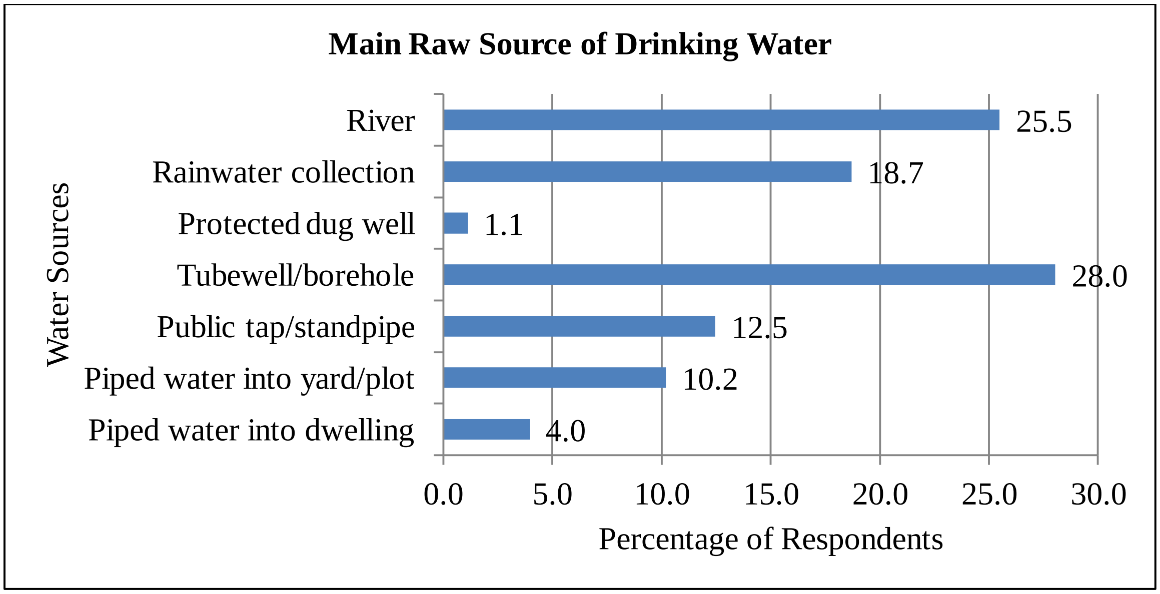


Figure 2. Main raw sources of drinking water.
Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017.

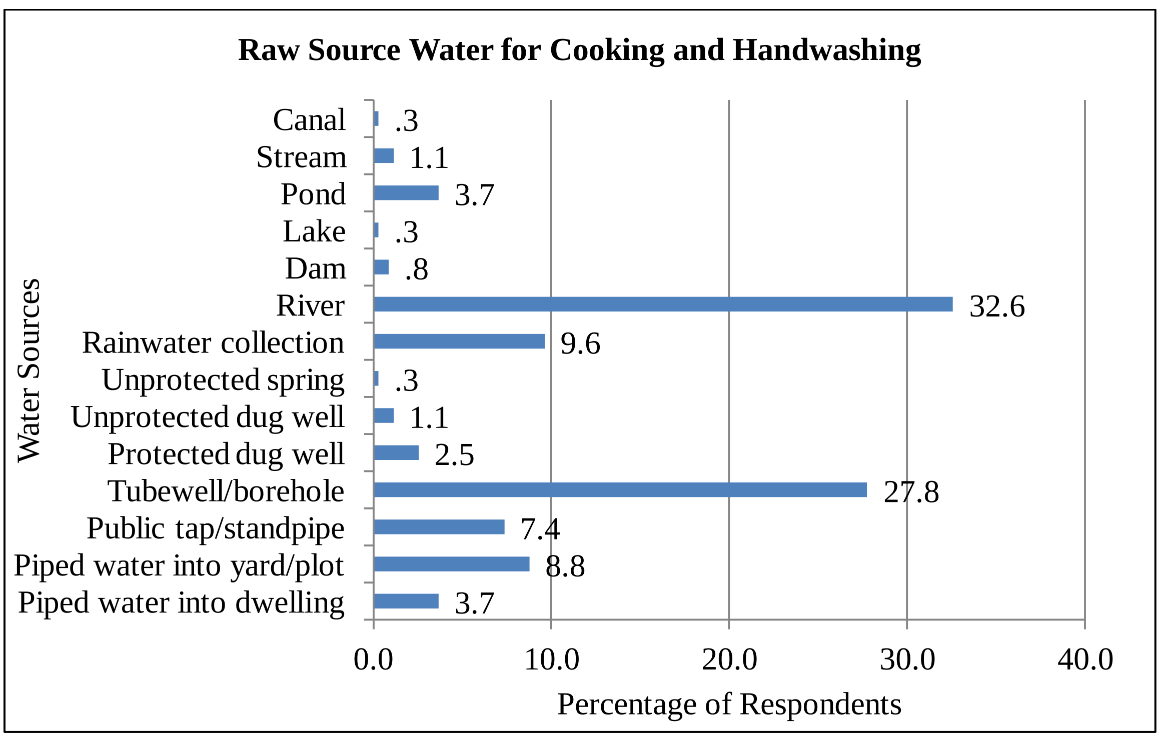


Figure 3. Raw source water for cooking and handwashing.
Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017.

Water collection. Adult women (83.9%) primarily fetch household water in Lower Nyakach. Female and male children (7.6% and 7.1%) share the burden of daily water collection followed by adult men (1.4%) who are mainly occupied with subsistence farming or migrant labor (see *Figure 4*). The majority of the population can collect their drinking water in under 30 minutes. Approximately 10% of the population takes over an hour to collect their drinking water. Only 3.4% have water on their premises (see *Figure 5*).

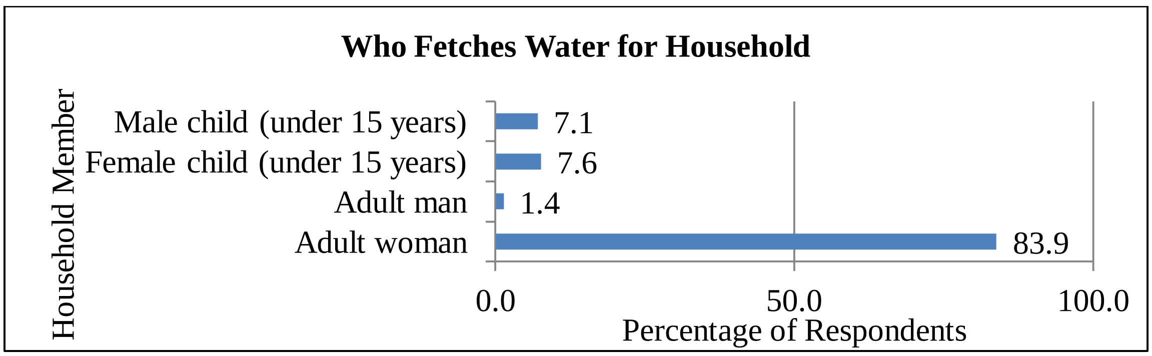


Figure 4. Who fetches water for household.
Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017.

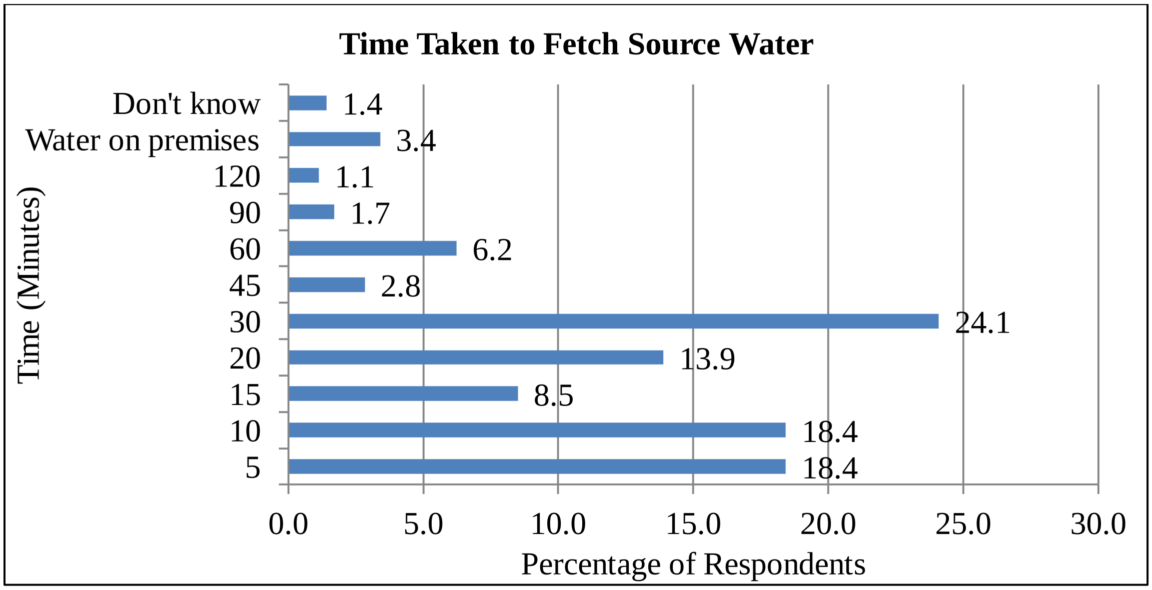


Figure 5. Time taken to fetch source water.
Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017.

Water treatment. Since the February 2012 introduction of the novel approach to water water treatment, the majority of households (95%) report treating their drinking water (see *Figure 6*). The preferred method of treatment is point-of-use chlorination using a 1.2% solution of bleach (see

Figure 7). The reported frequency of treatment is very promising with 86% of the population treating the drinking water every time it is collected. Those who occasionally treat their water are 10%. Only 4% of the respondents report rarely treating their water (see *Figure 8*). The JMP survey asked participants how long they have been using the treatment method. The time from the administration of the survey to the introduction of the EBM intervention was 66 months (February 2012 to August 2017) with 65.7% reporting not treating their drinking water before the introduction of the EBM intervention (see Figure 10).

For those respondents that chose chlorination as their primary method (92.1%), the target range of chlorine residual in home storage containers was between 0.2 – 4.0 mg/L of sodium hypochlorite with 57.9% of the home storage vessels demonstrating chlorine residual concentrations within the target range. Respondents whose drinking water concentration for chlorine residual did not meet the chlorine demand (i.e., underdosed) were 40.9%, and those who overdosed were 1.2%.

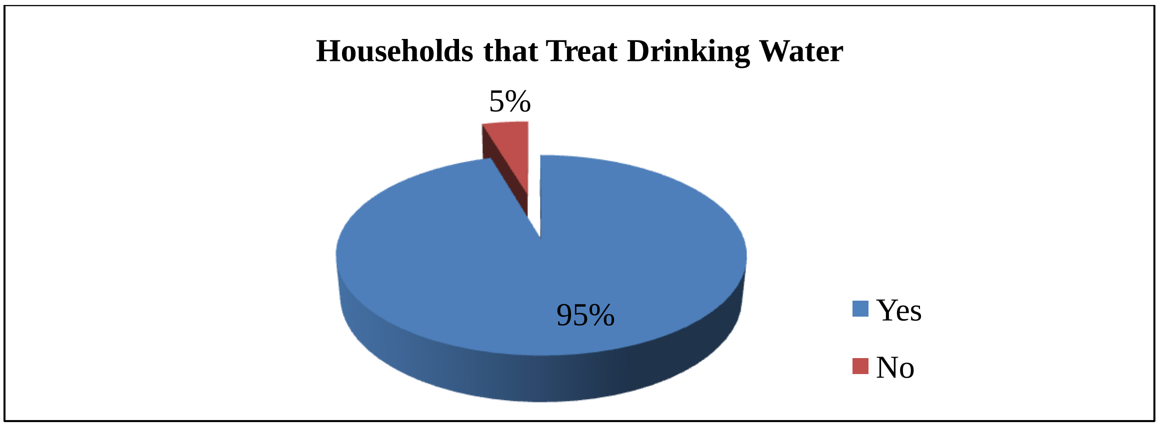


Figure 6. Households that treat drinking water.
Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017.

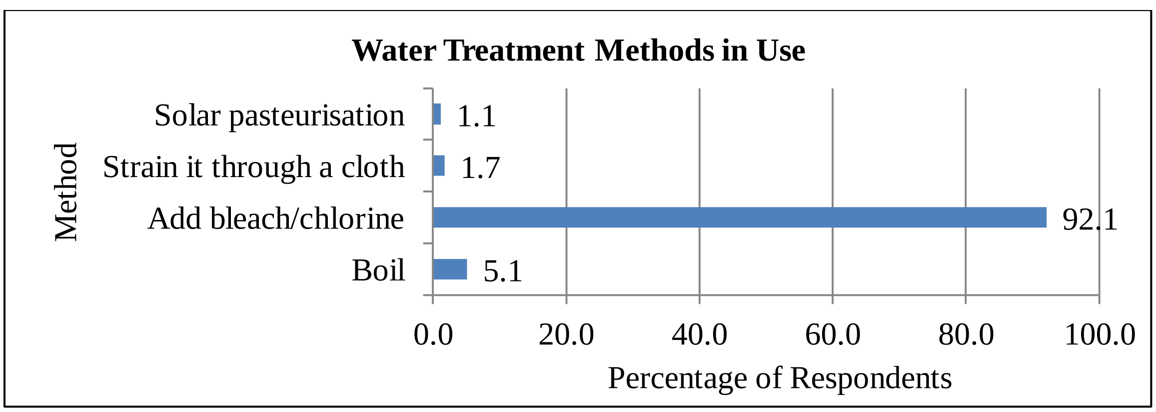


Figure 7. Water treatment methods in use.
The 1.1% of solar pasteurization users translates to 14% of those owning a solar cooker. An estimated 10% of the total households in Lower Nyakach own a solar cooker.
Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017.

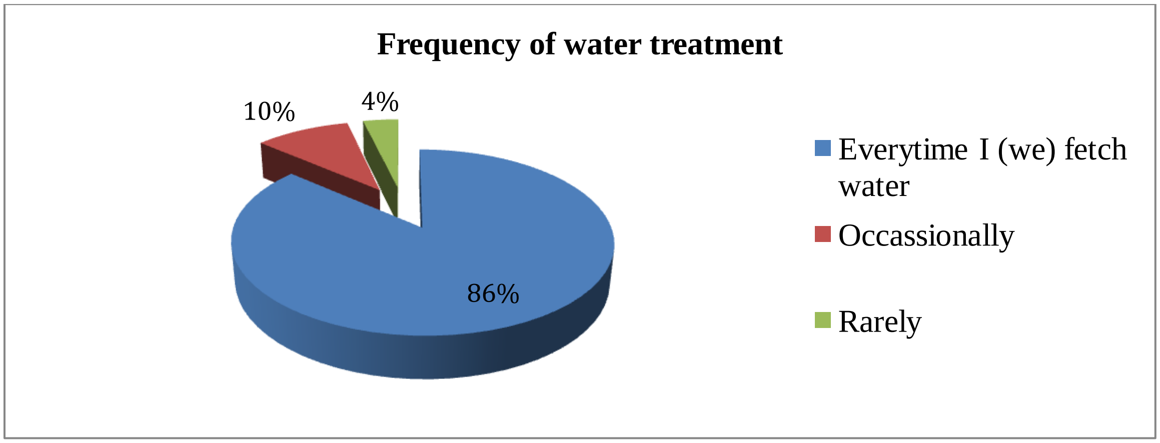


Figure 8. Households that treat drinking water.
Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017.

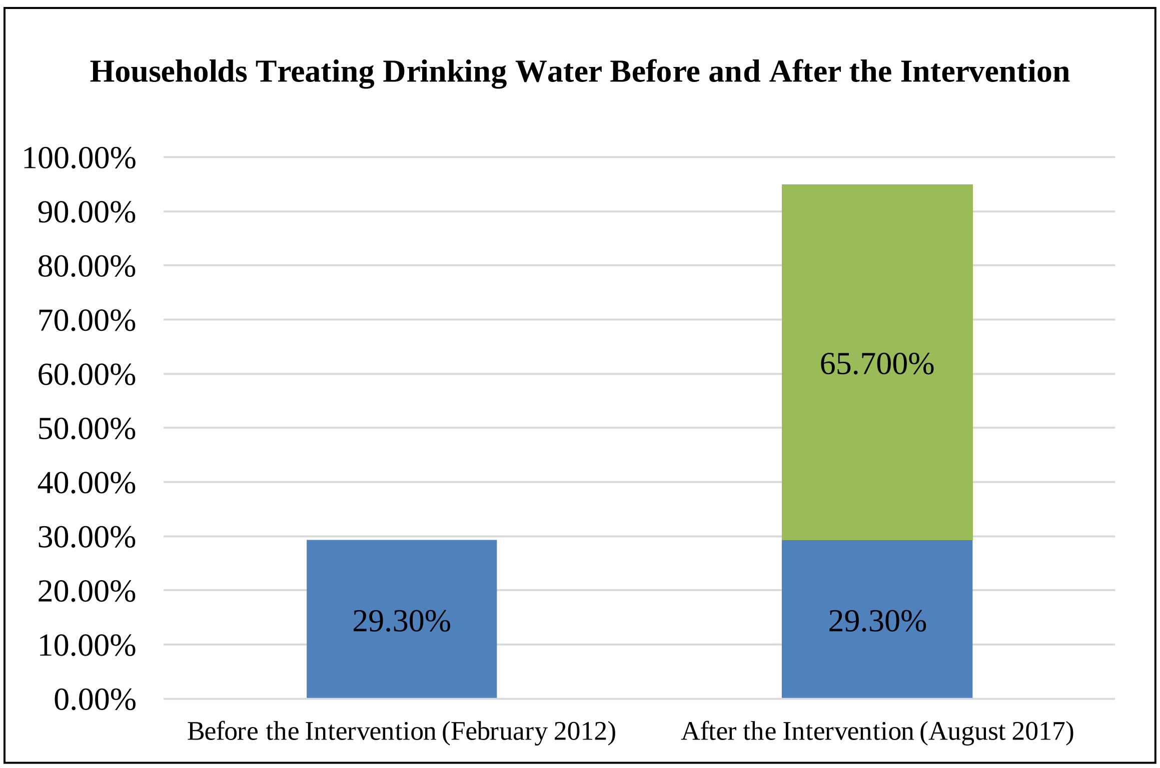


Figure 9. Households treating drinking water before and after the intervention.
Data courtesy of Nyando District Hospital, 2013 and JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017.

Water Storage. Responses to the presence of a safe storage vessel in households revealed that 90% of the population uses a ceramic or plastic container to store treated water (see *Figure 10*). A small portion (6.5%) of the population possesses the CDC, ceramic narrow mouth with spigot, safe water storage vessel (see *Figure 11*).

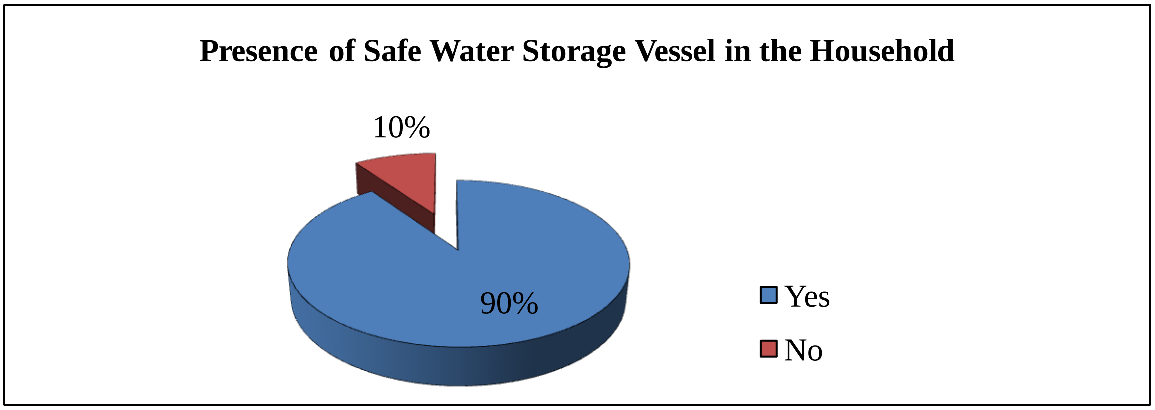


Figure 10. Presence of safe water storage vessel in the household.
Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017.

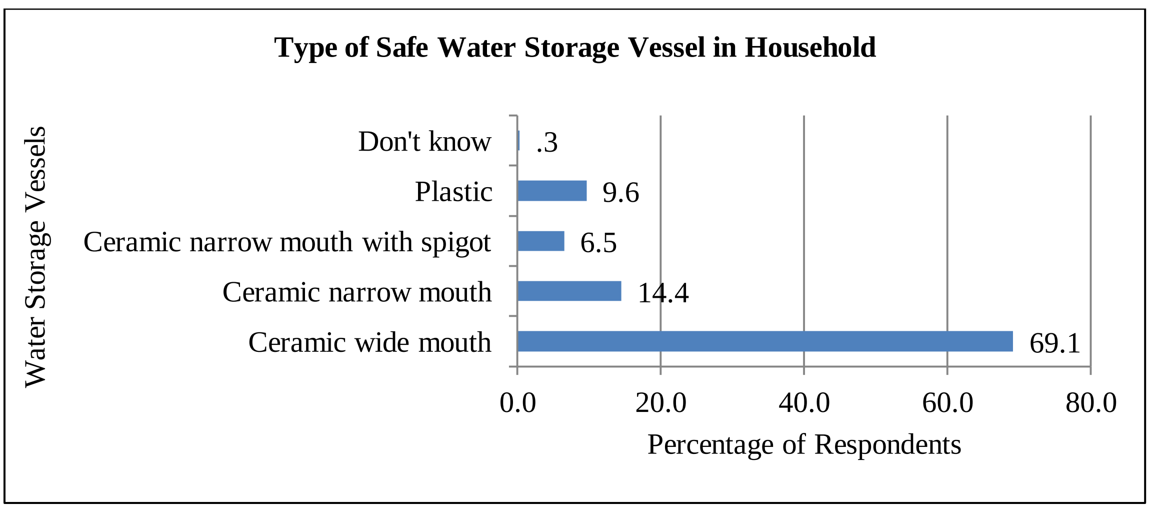


Figure 11. Type of safe water storage vessel in household.
Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017.

Results

This study used the self-reporting results from the JMP survey along with the bacteriological and chlorine residue evidence to answer the research questions stated:

RQ 1: Is there an association between the change in diarrhea morbidity in Lower Nyakach, Kenya, and the novel evidence-based microbiology intervention?

RQ 2: Is there an association in WHO risk of waterborne disease and the possession of a safe water vessel?

RQ 3: Is there a difference in WHO risk between solar pasteurization users and chlorine bleach users?

Research Question 1

Diarrhea trends from Pap Onditi Hospital, which services an estimated 140,000 population from the Nyakach region, show an average annual case admission rate of 84.3 cases/month (60.2/100K) before the 2012 introduction of the EBM intervention, compared to 33.9 cases/month (24.2/ 100K) for the three year post average. This represents a 59.7% decrease in diarrhea admissions at the district hospital since the evidence-based microbiology training was introduced to the community (see Figure 13). Monthly admission records for the district hospital demonstrate a sustained reduction in diarrhea cases among children under age 5 (see Figure 14).

Prior to the 2012 introduction of the intervention, 65.7% of respondents reported they did not treat their drinking water (see Figure 10), while 29.3% reported treating their water, but the consistency and effectiveness of treatment is not ascertainable.

A clear relationship between *E.coli* in drinking water and diarrhea has been established (Ercumen et al., 2017). This study uses the reasonable assumption that consuming safe water versus contaminated water is associated with lower diarrhea morbidity.

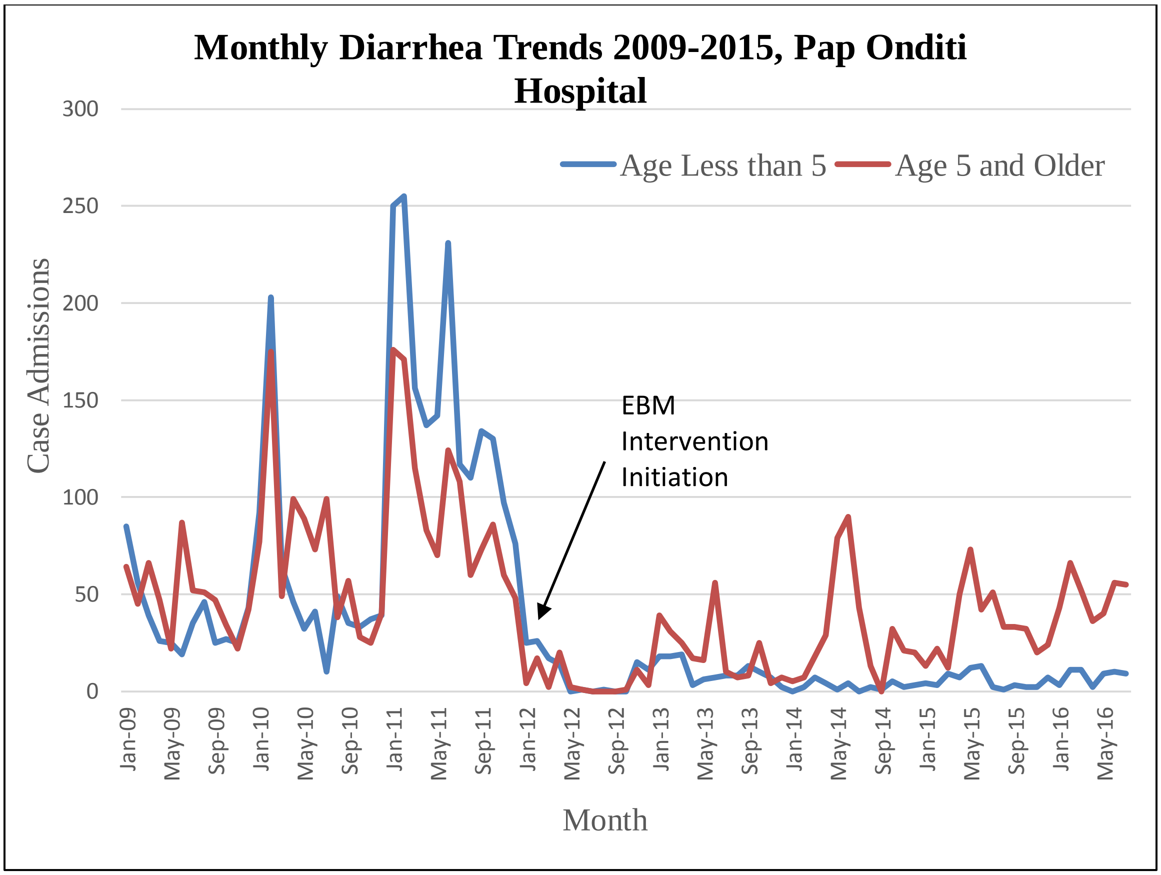


Figure 12. Monthly diarrhea trends 2009-2015, Pap Onditi Hospital.
Children 5 and older and adults show a sustained but variable reduction of diarrhea known as handwashing diseases. Children under 5 demonstrate sustained reduction of disease. Data courtesy Pap Onditi (Nyanado) District Hospital, Kenya, October 2017.

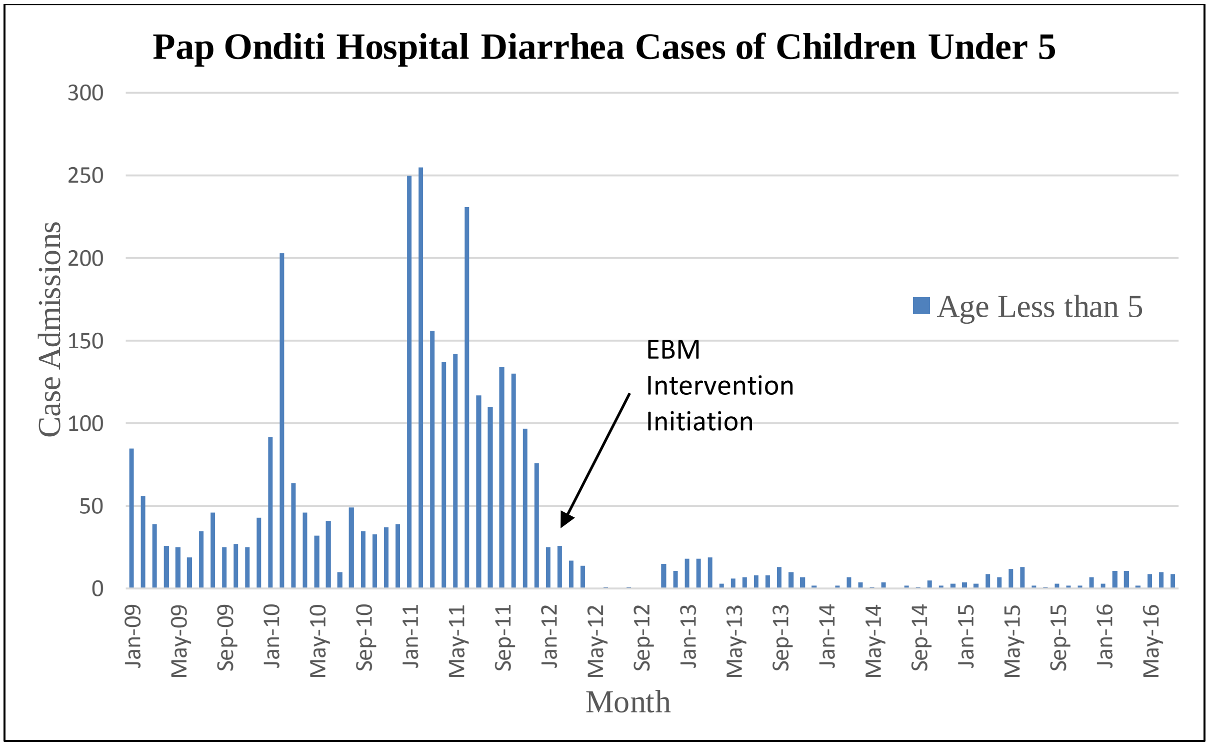


Figure 13. Pap Onditi Hospital diarrhea cases of children under 5.
The intervention appears to have been introduced during the natural decline of disease which does not recycle and remains in steady reduction of disease prevalence after the introduction of the novel EBM method. Data courtesy Pap Onditi (Nyanado) District Hospital, Kenya, October 2017.

Treatment and/or intervention fidelity. The evidence-based microbiology approach as adopted by FOTO followed the Teach, Test and Treat method of intervention implementation. The survey overwhelmingly reported that people feel their water is safe to drink in Lower Nyakach (see Figure *11*15), an area that historically is prone to cholera epidemics. Verification of the self-reporting was validated by the presence or absence and quantification of *E. coli* in the household drinking water. Test results verified that 88% had no *E.coli* in their water at the time of survey. Eight percent (8%) of the sampled households demonstrated the presence of environmental coliforms, with no *E.coli* in their water and only 4% of the population demonstrated the presence of *E. coli* (see Figure *11*16). Additionally, 95% of the respondents reported treating their drinking water (see Figure 7) with 86% treating each and every time a new batch was collected (see Figure 119).

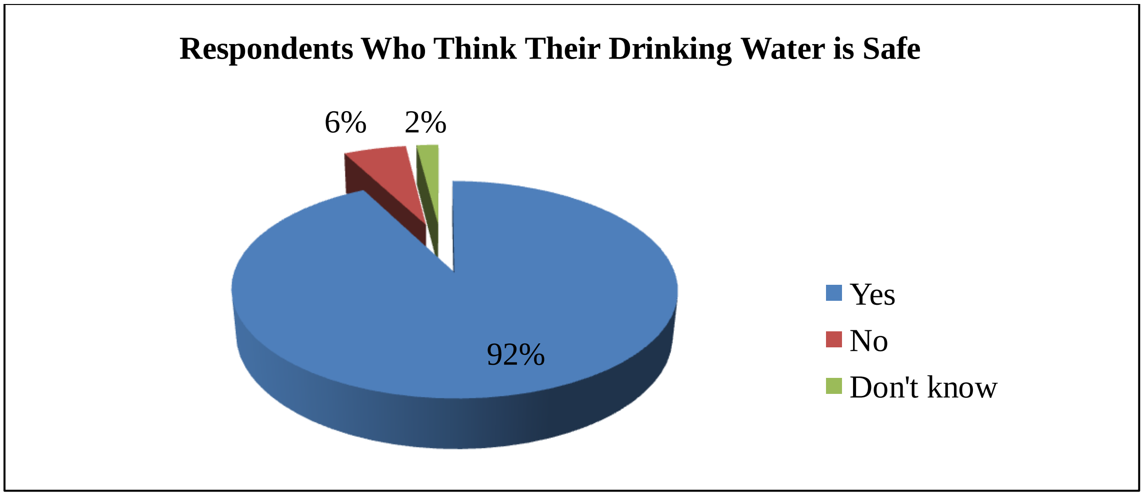


Figure 14. Respondents who think their drinking water is safe.
Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017.

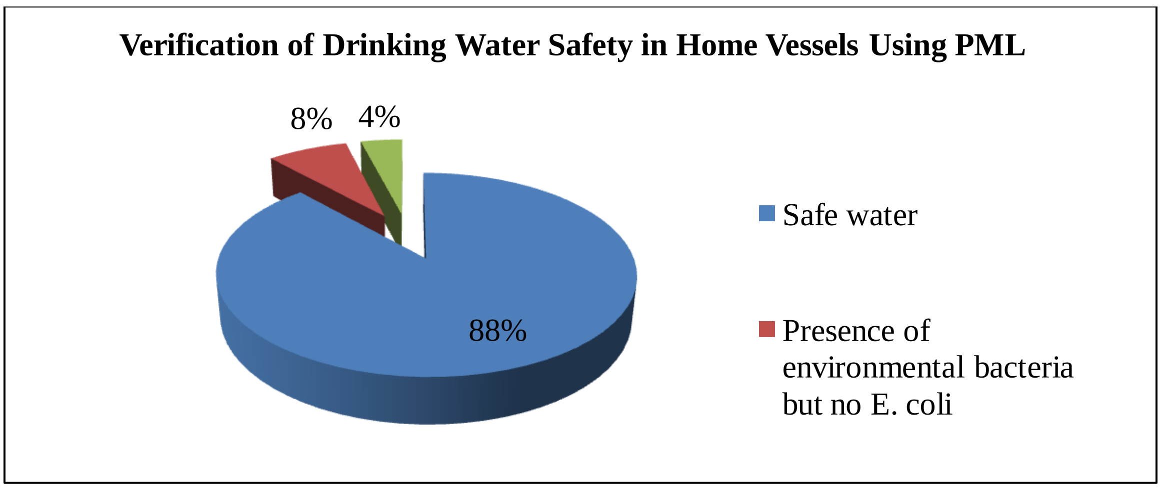


Figure 15. Verification of drinking water safety in home vessels using PML.
Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017.

Table 5

Possible Combinations of WHO Risk Level Compared to Exposure to EBM Training

Drinking Water Risk Level	Raw Water Risk Level	Number of Survey Respondents Before Intervention	Number of Survey Respondents After Intervention	Water Safety
Low	Low	-	-	-
Low	Moderate	-	-	-
Low	High	-	5	Safe
Low	Very High	112	219	Safe
Moderate	Low	-	-	-
Moderate	Moderate	-	-	-
Moderate	High	-	1	Unsafe
Moderate	Very High	2	-	Unsafe
High	Low	-	-	-
High	Moderate	-	1	Unsafe
High	High	-	1	Unsafe
High	Very High	12	7	Unsafe
Very High	Low	-	-	-
Very High	Moderate	-	1	Unsafe
Very High	High	4	2	Unsafe
Very High	Very High	5	7	Unsafe

Note: Safe water was determined by the concentration of E.coli in household drinking water at the time of survey using the PML.

Those survey respondents (65.7%) that did not treat their drinking water before the introduction of the EBM intervention (Feb.2012) are considered to have consumed water of "raw" water quality before training/help was given. Therefore, the quality of the "raw" water from the 2017 study was used in the database, which has a 76 % chance of a very high risk for disease (see Table 2, pg 20). An analysis of variance (see Figure 17) between verified water safety using the PML (see Figure 16) was compared to the EBM training influence on water safety (see Figure 10) and the average triennial diarrhea trends from Pap Onditi Hospital (see Figure 13).

Of the total number of respondents (n = 379) who reported treating their drinking water, 96% demonstrated safe water as indicated by the WHO Low Level of risk which was verified by the absence of *E.coli*. The presence of safe water compared to exposure to the EBM training showed high significance ($p<.001$) in individual households.

Table 6

Average Number of Households with Safe Drinking Water vs. Exposure to Training

EBM Training	Mean	N	Std. Deviation
No	.49	379	.501
Yes	.96	379	.207
Total	.72	758	.448

Note. Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017, SPSS: BlodgettDataXLS calculation courtesy of Gary Hulbert Data Sciences, Feb 2018

Table 7

Correlation between Training and Water Safety

		Training	Water Safety
Training	Pearson Correlation	1	.521**
	Sig. (1-tailed)		.000
	N	758	758
Water Safety	Pearson Correlation	.521**	1
	Sig. (1-tailed)	.000	
	N	758	758

Note. Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017, SPSS: BlodgettDataXLS calculation courtesy of Gary Hulbert Data Sciences, Feb 2018

Table 8

Analysis of Variance for EBM Training

ANOVA	Sum of Squares	df	Mean Square	F	Sig.
Regression	41.331	1	41.331	281.666	.000
Residual	110.934	756	.147		
Total	152.265	757			

Note. Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017, SPSS: BlodgettDataXLS calculation courtesy of Gary Hulbert Data Sciences, Feb 2018

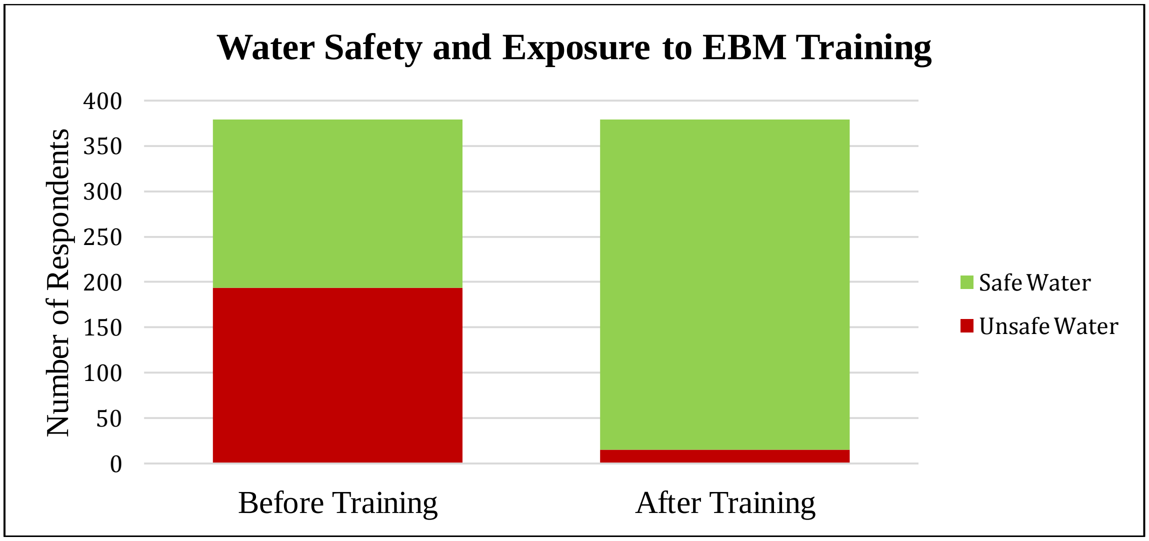


Figure 16. Water safety and exposure to EBM training.
Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017, Verification of Safety by *E. coli* analysis using the PML. SPSS: BlodgettDataXLS calculation courtesy of Gary Hulbert Data Sciences, Feb 2018.

Research Question 2

The majority of domestic water storage vessels in Lower Nyakach are ceramic pots that can hold 20 to 40 liters of water. The majority of containers in Lower Nyakach are open wide mouth (69%) followed by open narrow mouth (14.4%) and narrow closed mouth with a spigot (6.5%). The remainder of storage vessels tends to be the yellow plastic containers from water collected at the source.

Table 9

Possible Combinations of WHO Risk Level Compared to Vessel Type

Drinking Water Risk Level	Raw Water Risk Level	Ceramic Wide	Ceramic Narrow	Ceramic Narrow With Spigot	Plastic Vessel	Water Safety
Low	Low	-	-	-	-	-
Low	Moderate	-	-	-	-	-
Low	High	5	-	-	5	-
Low	Very High	228	49	23	28	Safe
Moderate	Low	-	-	-	-	-
Moderate	Moderate	-	-	-	-	-
Moderate	High	2	-	-	-	Unsafe
Moderate	Very High		-	-	-	Unsafe
High	Low	-	-	-	-	-
High	Moderate	-	1	-	-	Unsafe
High	High	1	-	-	-	Unsafe
High	Very High	13	3	1	1	Unsafe
Very High	Low	-	-	-	-	-
Very High	Moderate	-	1	-	-	Unsafe
Very High	High	1	-	-	1	Unsafe
Very High	Very High	10	-	-	1	Unsafe

Note. Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017.

Data bases were created to compare vessel type to water safety. **Error! Reference source not found.** compares water safety of wide mouth ceramic to narrow mouth ceramic vessels, which shows evidence (p = .004) that use of narrow mouth vessels increase the potential for safe water.

Table 10

Comparing Water Safety between Wide and Narrow Mouth Ceramic Vessels

Vessel	Mean	N	Std. Deviation
Wide Mouth	.46	256	.499
Narrow Mouth	.64	84	.482
Total	.51	340	.501

Note. Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017, SPSS: BlodgettDataXLS2 calculation courtesy of Gary Hulbert Data Sciences, Feb 2018

Table 11

Analysis of Variance for Vessel Type

ANOVA	Sum of Squares	df	Mean Square	F	Sig.
Regression	2.093	1	2.093	8.535	.004
Residual	82.895	338	.245		
Total	84.988	339			

Note. Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017, SPSS: BlodgettDataXLS2 calculation courtesy of Gary Hulbert Data Sciences, Feb 2018

The second data set from Table 9 compares narrow mouth (open lid) vessels to the CDC narrow mouth (closed lid) vessel with a spigot. This data (see Table 13) shows no evidence that closed lid narrow mouth vessels with a spigot provide safer water than open lid, narrow mouth vessels without a spigot (p = .41).

Table 12

Comparing Water Safety between Narrow Mouth Ceramic Vessels

Vessel	Mean	N	Std. Deviation
Narrow/No Spigot	.67	58	.473
Narrow/with Spigot	.58	26	.504
Total	.64	84	.482

Note. Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017, SPSS: BlodgettDataXLS2 calculation courtesy of Gary Hulbert Data Sciences, Feb 2018

Table 13

Analysis of Variance for Narrow Mouth Vessel Types

ANOVA	Sum of Squares	df	Mean Square	F	Sig.
Regression	.164	1	.164	.702	.405
Residual	19.122	82	.233		
Total	19.286	83			

Note. Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017, SPSS: BlodgettDataXLS2 calculation courtesy of Gary Hulbert Data Sciences, Feb 2018

Research Question 3

It is estimated that 10% of the population of Lower Nyakach possess the SWP which includes the Solar Cookit for water pasteurization. Of the 377 respondents surveyed, 15 reported owning a SWP which contained a Solar Cookit, but only 4 respondents used solar for water pasteurization - much lower than the expected representation.

The majority of the population chlorinates their drinking water and the majority of Solar Cookit owners prefer to use chlorine as the primary source of water treatment and solar pasteurization as a backup procedure thus freeing up the cooker for food preparation.

Analysis to determine the difference in water safety versus pasteurization and/or chlorination is found in Table 16 which data shows no evidence (p = .21) that there is any difference in the water safety effectiveness between the two treatment methods.

Table 14

Possible Combinations of WHO Risk Level Compared to Treatment Method

Drinking Water Risk Level	Raw Water Risk Level	Chlorine	Solar	Boil	Strain	Water Safety
Low	Low	-	-	-	-	-
Low	Moderate	-	-	-	-	-
Low	High	-	-	-	-	-
Low	Very High	306	4	19	4	Safe
Moderate	Low	-	-	-	-	-
Moderate	Moderate	-	-	-	-	-
Moderate	High	-	-	-	-	Unsafe
Moderate	Very High	3	-	-	-	Unsafe
High	Low	-	-	-	-	-
High	Moderate	1	-	-	-	Unsafe
High	High	1	-	-	-	Unsafe
High	Very High	19	-	-	1	Unsafe
Very High	Low	-	-	-	-	-
Very High	Moderate	1	-	-	-	Unsafe
Very High	High	2	-	-	-	Unsafe
Very High	Very High	12	-	-	1	Unsafe

Note. Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017.

Table 15

Comparing Water Safety between Chlorination and Solar Pasteurization Users

Vessel	Mean	N	Std. Deviation
Solar pasteurization	.33	15	.488
Chlorination	.50	362	.501
Total	.49	377	.501

Note. Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017, SPSS: BlodgettDataXLS3 calculation courtesy of Gary Hulbert Data Sciences, Feb 2018

Table 16

Analysis of Variance for Chlorination and Solar Pasteurization Users

ANOVA	Sum of Squares	df	Mean Square	F	Sig.
Regression	.387	1	.387	1.546	.214
Residual	93.831	375	.250		
Total	94.218	376			

Note. Data courtesy of JMP WHO/UNICEF Survey, Lower Nyakach, Kenya, August 2017, SPSS: BlodgettDataXLS3 calculation courtesy of Gary Hulbert Data Sciences, Feb 2018

Summary

RQ 1: The average three-year diarrhea trends, pre and post introduction of the novel intervention, demonstrated a 59.7% decrease (not adjusted for population growth) in reported case admissions from the district hospital archives (see Figure 13). The 2017 JMP survey results overwhelming reported that people feel their water is safe to drink in Lower Nyakach (92%), an area that historically is prone to cholera epidemics (see Figure 14). Verification of the self-reporting was validated by the presence of *E. coli* in the household drinking water using the PML (Metcalf, 2010). Test results demonstrated that 88% of the population had no *E. coli* in their water at the time of survey. Eight percent (8%) of the sampled households demonstrated the presence of environmental coliforms, with no *E. coli* in their water and only 4% of the population demonstrated the presence of *E.coli* (see Figure 15).

Survey results report 95% of the population treat their drinking water (see Figure 15) with 65.7% treating after they had been introduced to the EBM behavioral change communication program by FOTO (see Figure 10).

RQ 2**:** The safe water storage vessel developed by CDC, comprising of a ceramic container with a spigot, narrow neck and tight fitting lid, was present in 6.5% of the population surveyed (see Figure 12). The drinking water tested from these vessels demonstrated a low level of risk for disease compared to the raw water sources collected for these households which showed very high risk for waterborne disease. Similar results were found for the wide mouth and narrow mouth ceramic vessels as well as for those who stored their treated water in the yellow plastic 20 liter containers used to collect water.

RQ 3: Most people prefer to use chlorine as the primary source of water treatment and solar pasteurization as a backup procedure thus freeing up the cooker for food and family meal preparation, thus only 4% of Solar Cookit owners reported using it for water pasteurization (see Figure 8). I found no difference in WHO risk between solar pasteurization users and chlorine bleach users ($p = .21$) even though 41% of those reporting to use chlorine, demonstrated no chlorine residual in their home water storage system at the time of survey.

Conclusions from these finding will be discussed in Chapter 5. I will explore how the high compliance of treating domestic water, storage of safe drinking water, and the treatment method of choice support or challenge the hypotheses posed by the research questions.

Chapter 5: Conclusions

Introduction

In this chapter, I interpret the findings described in Chapter 4. I also discuss the limitation of the study and recommendations for further inquiry. An evaluation of the implications of this study to promote social change to improve the human condition will be followed by concluding remarks.

The purpose of this study was to evaluate the effectiveness of a novel evidence-based microbiological approach to reduce waterborne disease in an impoverished community of Kenya. The ability to verify the safety of water by laboratory testing in rural areas has been the missing link in WHO risk analysis. The nature of this study utilizes the vetted JMP drinking water health and habits survey and uses the PML as the tool to verify household water potability and accuracy of JMP survey results.

Key findings demonstrated a 59.7% decrease in diarrhea since the advent of the novel EBM intervention. Drinking water safety compared to the EBM training exposure ($p < .001$) demonstrated that 95% of the population was in compliance to treat their drinking water and prevent the stored water from becoming re-contaminated.

Interpretation of the Findings

The FOTO evidence-based microbiological approach has had widespread coverage throughout the area of Lower Nyakach, Kenya. Since the introduction of the intervention in February 2012, there has been a 95% acceptance of the health campaign to treat water, with 86% of the study population reporting treating their drinking water each and every time it is collected from the highly contaminated raw water source.

The main decrease in diarrhea cases is found in children under 5 years of age. A possible explanation is that the children drink water mainly from the home where water is treated. Adults who travel may ingest additional sources of water that may not have been treated. This study does not rule out the influence of non-waterborne illness causing diarrhea or the influence of patients from Upper Nyakach who use the district hospital and have not been introduced to the novel EBM approach.

Due to medical privacy issues, there is no practical way to directly correlate evidence-based microbiology intervention (with its associated training) to lower diarrhea morbidity; however, the sustained decrease in diarrhea trends from medical facilities throughout the region and the acceptance and practice of water treatment methods suggests an association between the decrease in waterborne disease and the EBM approach. There is significant evidence ($p < 0.001$) that the training and help provided from the novel EBM intervention has a positive influence on water safety to the people of Lower Nyakach.

There appears to be little difference in the level of risk and the type of container in which to store water. General knowledge supposes that water should be safer in a closed system that resists recontamination from human or animal activity, but this study did not establish a difference in vessel type and risk. A possible explanation for not establishing a difference between the container type and risk is due to the excellent coverage of the FOTO public health campaign. With 95% compliance in treating drinking water, many people are now aware of the fecal-oral route of contamination in Lower Nyakach, and may not recontaminate their drinking water.

Most people prefer to use chlorine as the primary source of water treatment and solar pasteurization as a backup procedure, thus freeing up the solar cooker for food and family meal preparation. *E.coli* is the water industry standard for determining safety but is not an ideal indicator for all possible pathogens of fecal origin. It is known that heat, by boiling or pasteurization, kills all pathogens that can cause waterborne disease, but chlorination is only partially effective against certain protozoa and will not inactivate Cryptosporidium and Schistosomes at drinking water concentrations.

The low level of chlorine residual in 41% of respondents' drinking water suggests possible inadequate disinfection by failure to satisfy the chlorine demand. *E. coli* verification counts showed that 88% of the population surveyed had safe water (WHO low level risk) and that 8% had environmental coliforms without the presence of *E.coli* (see Figure 15). These data suggest that even underdosing of chlorine in this region has a beneficial effect on reducing waterborne disease. The findings of no difference (p = .21) between treatment methods must be taken in the context of *E.coli* inactivation. Heat is still considered the superior disinfection method, but the introduction of chlorination to this community appears to have greatly reduced the burden of waterborne disease transmission.

Limitations of the Study

Analyses of the *E.coli*–diarrhea association are observational and can be confounded. Most studies measure water quality cross-sectionally with diarrhea, risking exposure misclassification and reverse causation. Sanitation and hygiene conditions may impact household water quality and independently impact diarrhea via non-waterborne transmission.

To reduce courtesy bias, I verified self-reporting of water treatment with *E.coli* counts using the PML. To establish a comparison group, I assumed that those who did not treat their drinking water before the 2012 intervention were considered to have consumed water of raw source quality posing a threat to external validity due to the interaction of history and treatment. These data may be subject to recall bias that cannot be verified; thus causation, from a quantitative sense, cannot be established. Nonetheless, the strong association of respondents' self-reported drinking water habits compared to the EBM verification of drinking water safety, demonstrated a general trustworthiness and reliability of survey measures throughout the population.

Recommendations

I have found that the "3T" method using evidence-based microbiology is an effective behavioral change communication model. I propose that a 3-year longitudinal study comparing pre and post intervention results with baseline assessment of disease prevalence and treatment practices be conducted to better establish a causal link between treating raw water each and every time it is collected and the reduction of waterborne disease in a community.

The establishment of a partnership with a grounded CBO is essential to the success of behavior change. We recommend teaching the basic science of disease interruption and providing appropriate treatment methods to the community.

Implications

Waterborne disease is 100% preventable—kill the germs with heat or chlorine and people do not get sick. The key to the EBM approach is the acceptance and training provided by a well-established CBO to own and facilitate the health program. In this study, the PML was introduced into communities with a workshop that included a teaching component that demystifies microbiology. Subsequent community testing of water sources before and after pasteurization or chlorination provided evidence-based microbiology data about water sources and effective household treatment methods. The tests also provided feedback to health agencies.

Conclusion

We found evidence of a strong relationship between the reduction of diarrhea and the novel EBM strategy introduced at the community level. The EBM approach is a viable behavioral change communications method that has a 95% acceptance and success rate in Lower Nyakach, which has a population of 70,000. The dramatic visual results of the PML testing of drinking water sources before and after treatment led to a community understanding that drinking water sources were contaminated, and that heat or chlorine kills the germs and makes the water safe to drink. This method may be replicated throughout the world and provide a roadmap to governments and nonprofits to decrease the scourge of waterborne disease among the poorest people in the world.

References

Alekal, P. (2005). *Appropriate water treatment for the Nyanza Province of Kenya*. (Unpublished master's thesis). Massachusetts Institute of Technology, Cambridge, MA.

Allen, M., Payment, P., & Clancy, J. (2010). Rapid microbial methods can improve public health protection. *Journal: American Water Works Association, 102*(8), 44-51. doi:10.1002/j.1551-8833.2010.tb10169.x

Arnold, B. F., & Colford, J. M. (2007). Treating water with chlorine at point-of-use to improve water quality and reduce child diarrhea in developing countries: A systematic review and meta-analysis. *The American journal of tropical medicine and hygiene*, 354-364.

Bain, R., Gundry, S., Wright, J., Yang, H., Pedley, S., & Bartram, J. (2011). Accounting for water quality in monitoring access to safe drinking-water as part of the Millennium Development Goals: lessons from five countries. *Bulletin World Health Organization*. doi:10.2471/BLT.11.094284

Barzilay, E., Aghoghovbia, T., Blanton, E., Akinpelumi, A., Coldiron, M., Akinfolayan, O., . . . Quick, R. (2011, March). Diarrhea prevention in people living with HIV: an evaluation of a point-of-use water quality intervention in Lagos, Nigeria. *AIDS care, 23*(3), 330-339. doi:10.1080/09540121.2010.507749

Blakely, T., Hales, S., Kieft, C., Wilson, N., & Woodward, A. (2005). The global distribution of risk factors by poverty level. *Bulletin of the World Health Organization*, *83*(2), 118-126.

Blanton, E., Ombeki, S., Oluoch, G., Mwaki, A., Wannemuehler, K., & Quick, R. (2010). Evaluation of the role of school children in the promotion of point-of-use water treatment and handwashing in schools and households--Nyanza Province, Western Kenya, 2007. *The American Society of Tropical Medicine and Hygiene, 82*(4), 664-671. doi:10.4269/ajtmh.2010.09-0422

Brown, J., & Clasen, T. (2012). High adherence is necessary to realize health gains from water quality interventions. *PLoS ONE, 7*(5). doi:10-1371/journal.pone.0036735.

Chienjo, D. (2013). The goal is zero: a strategy to eliminate water-borne disease in Lower Nyakach, Kenya. Presented at the International Water Association's 3rd Development Congress. Nairobi, Kenya.

Ciochetti, D., & Metcalf, R. (1984). Pasteurization of naturally contaminated water with solar energy. *Applied & Environmental Microbiology, 47*(2), 223-228.

Clasen, T., Roberts, I., Rabie, T., Schmidt, W., & Cairncross, S. (2006). Interventions to improve water quality for preventing diarrhoea (review). *Cochrane Database of Systematic Reviews*(3). doi:10.1002/14651858.CD004794.pub2

Clasen, T., Schmidt, W., Rabie, T., Roberts, I., & Cairncross, S. (2007). Interventions to improve water quality for preventing diarrhea: systematic review and meta-analysis. *BMJ*, 782-791. doi:10.1136/bmj39118.489931.BE

DHS. (2009). *N., Kenya and MEASURE DHS, ICF Macro.* Kenya National Bureau of Statistics, Kenya. Calverton, Maryland: DHS, 2008-09, Final Report.

Doyle, M., & Erickson, M. (2006). Closing the door on the fecal coliform assay. *Microbe*, 1(4), 162-163.

DuBois, A., Crump, J., Keswick, B., Slutsker, L., Quick, R., Vulule, J., & Luby, S. (2010). Determinants of Use of Household-level Water Chlorination Products in Rural Kenya, 2003-2005. *International Journal of Environmental Research and Public Health, 7*, 3842-3852. doi:10.3390/ijerph7103842

Edberg, S., Rice, E., Karlin, K., & Allen, M. (2000). Escherichia coli: the best biological drinking water indicator for public health protection. *Journal of Applied Microbiology*, 68, 106-116.

Esrey, S. H. (1986). Epidemiologic evidence for health benefits from improved water and sanitation in developing countries. *Epidemiol Review*, 8, 117-28.

Etheridge, S. (2015). *Identifying cultural themes in a shared experience of water hygiene education partners*. (Unpublished doctoral dissertation). Walden University, Minneapolis, MN.

Fewtrell, L., Kaufmann, R., Kay, D., Enanoria, W., Haller, L., & Colford, J. (2005). Water, sanitation, and hygiene interventions to reduce diarrhea in less developed countries: a systematic review and meta-analysis. *The Lancet*, 5, 42-52.

Fielbelkorn, A., Person, B., Quick, R., Vindigni, S., Jhung, M., Bowen, A., & Riley, P. (2012). Systematic review of behavior change research on point-of-use water treatment interventions in countries categorized as low- to medium-development on the human development index. *Social Science & Medicine*, 1-12. doi:10.1016/j.socscimed.2012.02.011

Garrett, V., Ogutu, P., Mabonga, P., Ombeki, S., Mwaki, A., Aluoch, G., . . . Quick, R. (2008). Garrett V, Ogutu P, Mabonga P, Ombeki Diarrhoea prevention in a high-risk rural Kenyan population through point-of-use chlorination, safe water storage, sanitation, and rainwater harvesting. *Epidemiol Infect, 136*(11), 1463-1471.

Gerstman, B. (2008). *Basic Biostatistics: Statistics for public health practice.* Sudbury, Mass: Jones and Bartlett.

Gilman, R., & Skillicorn, P. (1985). Boiling of drinking water: can a fuel-scarce community afford it? *Bulletin of the World Health Organization*, 63, 157-163.

Guiteras, R., Levinsohn, J., & Mobarak, A. (2015). Encouaging sanitation investment in the developing world: A cluster-randomized trial. *Science, 348*(6237), 903-906. doi:Guiteras, R., Levinsohn, J., and Mobarak, A.M. (2015). Encouaging sanitation investment in th10.1126/science.aaa5727

Harris, J., Patel, M., Juliao, P., Suchdev, P., Ruth, L., Were, V., . . . Quick, R. (2012). Addressing inequities in access to health products through the use of social marketing, community mobilization, and local entrepreneurs in rural western Kenya. *International Journal of Population Research*. doi:10.1155/2012/470598

Lantagne, D., Quick, R., & Mintz, E. (2006). Household Water Treatment and Safe Storage Options in Developing Countries: A Review of Current Implementation Practices. *U.S. Centers for Disease Control and Prevention*.

Lantange, D. (2008). Sodium hypochlorite dosage for household and emergency water treatment. *Journal American Water Works Association, 100*(8), 106-119. Retrieved from https://www.wilsoncenter.org/sites/default/files/WaterStoriesHousehold.pdf

Levy, K., Nelson, K., Hubbard, A., & Eisenberg, J. (2012). Rethinking indicators of microbial drinking water quality for health studies in tropical developing countries: Case study in Northern Coastal Ecuador. *American Journal of Tropical Medicine Hygeine, 86*(3), 499-507. doi:10.4269/ajtmh.2012.11-0263

Markovitz, A., Goldstick, J., Levy, K., Cevallos, W., Mukherjee, B., Trostle, J., & Eisenberg, J. (2012). Where science meets policy: comparing longitudinal and cross-sectional designs to address diarrhoeal disease burden in the developing wor. *International Journal of Epidemiology, 41*, 504-513. doi:10.1093/ije/dyr194

Médecins Sans Frontières. (1994). Public Health Engineering in Emergency Situations.

Metcalf, R. (2013, November 21-23). Comments on draft report of WHO/UNICEF joint monitoring program task force meeting (Unpublished). Geneva, Switzerland.

Metcalf, R., & Stordal, L. (2010). *A practical method for rapid assessment of the bacterial quality of water*. (HS Number: HS/179/10E). Retrieved from United Nations Human Settlements Programme (UN-HABITAT) website: http://www.unhabitat.org/pmss/listItemDetails.aspx?publicationID=3056

National Council for Science and Technology. (2004). Guidelines for Ethical Conduct of Biomedical Research Involving Human Subjects in Kenya. Retrieved from https://webapps.sph.harvard.edu/live/gremap/files/ke_NCST_guidelines.pdf

Ogutu, P., Garrett, V., Barasa, P., Ombeki, S., Mwaki, A., & Quick, R. (2001). Seeking Safe Storage: A Comparison of Drinking Water Quality in Clay and Plastic Vessels. *American Journal of Public Health, 91*(10).

Onda, K., LoGuglio, J., & Bartram, J. (2012). Global access to safe water: accounting for water quality and the resulting impact on MDG progress. *International Journal of Environmental Research and Public Health*, doi:10.3390/ijerph9030880.

Onjala, J., Ndiritu, S., & Stage, J. (2014). Risk perception, choice of drinking water and water treatment: evidence from Kenyan towns. *Journal of Water Sanitation and Hygiene for Development, 4*(2), 268-280. doi:10.2166/washdev.2014.131

Parker, K. (2011). *Bacterial contamination of drinking water in rural Ghana*. (Unpublished master's thesis). California State University, Sacramento, CA.

Preez, M., Conroy, R., Wright, J., Moyo, S., Potgieter, N., & Gundry, S. (2008). Short report: use of ceramic water filtration in the prevention of diarrheal disease: a randomized controlled trial in rural South Africa and Zimbabwe. *American Society of Tropical Medicine and Hygiene, 79*(5), 696-701.

Rosa, G., & Clasen, T. (2010). Estimating the scope of household water treatment in low- and medium-income countries. *American Journal of Tropical Medicine and Hygiene*, *82*(2), 289-300. doi:10.4269/ajtmh.2010.09-0382

Safapour, N., & Metcalf, R. (1999). Enhancement of Solar Water Pasteurization with Reflectors. *Applied and Environmental Microbiology, 65*, 859-861.

Safe Water and AIDS Project (SWAP). (2012). *Annual report, Kisumu, Kenya.* Retrieved from http://www.swapkenya.org

Simpson-Hebert, M., Sawyer, R., & Clarke, L. (2000). The PHAST Initiative: Participatory hygiene and sanitation transformation, a new approach to working with communities. *UNDP-World Bank Water and Sanitation Program*.

Sobsey, M. (2002). *Managing water in the home: accelerated health gains from improved water supply*. (WHO/SDE/WSH/2.07). Retrieved from World Health Organization website: http://www.who.int/water_sanitation_health/dwq/WSH02.07.pdf

Sobsey, M., Stauber, C., Casanova, L., Brown, J., & Elliott, M. (2008). Point of use household drinking water filtration: a practical, effective solution for providing sustained access to safe drinking water in the developing world. *Environmental Science & Technology, 42*(12), 4261-4267.

Solar Cookers International. (2008). *Sunny Solutions Project Evaluation, Nyakach, Kenya: Nyando District development program 2003-2008*. Retrieved June 15, 2014, from http://www.solarcookers.org/programs/multkenya.html

Standridge, J. (2008). E. coli as a public health indicator of drinking water quality. *Journal: American Water Works Association*, *100*(2), 65-75.

Suchdev, P., Ruth, L., Obure, A., Vincent, W., Ochieng, C., Ogange, L., . . . Jefferda, M. (2010). Monitoring the marketing, distribution, and use of Sprinkled micronutrient powders in rural western Kenya. *Food and Nutrition Bulletin, 31*(2).

United Nations. (2013). *The Millennium Development Goals Report.* Retrieved from http://www.un.org/millenniumgoals/pdf/report-2013/mdg-report-2013-english.pdf

Waddington, H., & Snilstveit, B. (2009). Effectiveness and sustainability of water, sanitation, and hygiene interventions in combating diarrhoea. *The Journal of Development Effectiveness*, *1*(3), 295-335. doi:10.1080/19439340903141175

White, G. (1999). *Handbook of chlorination and alternative disinfectants.* New York, New York: John Wiley & Sons, Inc.

WHO. (2005). *The world health report: Make every mother and child count.* Geneva. Retrieved from www.who/intf/whr2005_en

WHO. (2008). *Guidelines for Drinking Water Quality*. Geneva.

WHO. (2013). *Household water treatment and safe storage: Manual for the participant.* Regional Office for the Western Pacific. Retrieved from www.wpro.who.int

WHO. (2014). *World health statistics 2014.* Retrieved from www.who/int

WHO/UNICEF. (2006a). Meeting the MDG drinking water and sanitation target: the urban and rural challenge of the decade. *Joint Monitoring Programme for Water Supply and Sanitation,* 23-24.

WHO/UNICEF. (2006b). Core questions on drinking water and sanitation for household surveys. *Joint Monitoring Programme for Water Supply and Sanitation*, 3-24. Retrieved from www.wssinfo.org

WHO/UNICEF. (2010a). Progress on sanitation and drinking-water, 2010 update. *Joint Monitoring Programme for Water Supply and Sanitation*.

WHO/UNICEF. (2010b). MP Technical Task Force meeting on monitoring drinking-water quality, 16-18 November 2010, Chateau de Pizay, Villié-Morgon, France : report. Villié-Morgon: World Health Organization (WHO). Retrieved from https://www.ircwash.org/sites/default/files/jmp-task-force-meeting-on-monitoring-drinking-water-quality.pdf

WHO/UNICEF. (2012). A Toolkit for Monitoring and Evaluation Household Water Treatment and Safe Storage Programmes. 62.

WHO/UNICEF. (2015). Progress on sanitation and drinking-water, 2015 update. *Joint Monitoring Programme for Water Supply and Sanitation*.

Appendix A: BWF Water & Sanitation Survey for FOTO Project

BWF Water & Sanitation Survey for FOTO Project, Lower Nyakach, Kenya

Today's Date ☐

Survey Start Time ☐

Survey End Time ☐

for office use only

Geocode ☐

VAF # ☐

Q1 **What is the main source of drinking water for members of your household?**

- ☐ Piped water into dwelling
- ☐ Piped water into yard/plot
- ☐ Public tap/standpipe
- ☐ Tubewell/borehole
- ☐ Protected dug well
- ☐ Unprotected dug well
- ☐ Protected spring
- ☐ Unprotected spring
- ☐ Rainwater collection
- ☐ Bottled water
- ☐ Cart with small tank/drum
- ☐ Tanker-truck
- ☐ Surface water
  - ☐ river
  - ☐ dam
  - ☐ lake
  - ☐ pond
  - ☐ stream
  - ☐ canal
  - ☐ irrigation channels
- ☐ Other (specify) ____

Geocode of Source (to be ascertained by VAF) ☐

(VAF Comments)

Today's Date [ ]

VAF # [ ]

[ ] for office use only

Q1A **What is the main source of water used by your household for other purposes, such as cooking and hand washing?**

- [ ] Piped water into dwelling
- [ ] Piped water into yard/plot
- [ ] Public tap/standpipe
- [ ] Tubewell/borehole
- [ ] Protected dug well
- [ ] Unprotected dug well
- [ ] Protected spring
- [ ] Unprotected spring
- [ ] Rainwater collection
- [ ] Bottled water
- [ ] Cart with small tank/drum
- [ ] Tanker-truck
- [ ] Surface water
  - [ ] river
  - [ ] dam
  - [ ] lake
  - [ ] pond
  - [ ] stream
  - [ ] canal
  - [ ] irrigation channels
- [ ] Other (specify) ____

Geocode(s) of Source(s) [ ]

Q2 **How long does it take to go there, get water, and come back?**

- [ ] Number of minutes: _____________
- [ ] Water on premises
- [ ] Don't know

Q3 **Who usually goes to this source to fetch the water for your household?**

- [ ] Adult woman
- [ ] Adult man
- [ ] Female child (under 15 years)
- [ ] Male child (under 15 years)
- [ ] Don't know

Q4 **Do you treat your water in any way to make it safer to drink?**

- [ ] Yes
- [ ] No
- [ ] Don't know

Today's Date

VAF #

for office use only

Q5 What do you usually do to the water to make it safer to drink?

- [ ] Boil
- [ ] Add bleach/chlorine
- [ ] Strain it through a cloth
- [ ] Use a water filter (ceramic, sand, composite etc…)
- [ ] Solar disinfection
- [ ] Solar pasteurization
- [ ] Let it stand and settle
- [ ] Other (specify) ________________________________
- [ ] Don't know

Q5A How long have you been using this method? _________ **months**

Q5B How often do you use this method?

- [ ] Every time I (we) fetch water.
- [ ] Occasionally
- [ ] Rarely
- [ ] Don't know

Q5C Is there a safe water storage vessel in your home?

- [ ] Yes
- [ ] No
- [ ] Don't know

Q5D If yes, what type of vessel do you own?

- [ ] Ceramic wide mouth
- [ ] Ceramic narrow mouth
- [ ] Ceramic narrow mouth with spigot
- [ ] Plastic
- [ ] Other (specify) ________________________________
- [ ] Don't know

Q5E **Has anyone in this home recently had stomach pains or illness?**

- ☐ No
- ☐ Yes, in last two weeks
- ☐ Yes, in last month
- ☐ Yes, in last 3 months
- ☐ Don't know

Q5F **Do you think your water is safe to drink?**

- ☐ Yes
- ☐ No
- ☐ Don't know

Today's Date ☐ **VAF #** ☐ ☐

for office use only

Q6 **What Kind of toilet facility do members of your household usually use?**

- ☐ Flush/pour to flush
  - ☐ Piped sewer system
  - ☐ Septic tank
  - ☐ Pit latrine
  - ☐ Elsewhere
  - ☐ Unknown place/not sure/unknown
- ☐ Ventilated improved pit latrine (VIP)
- ☐ Pit latrine with slab
- ☐ Pit latrine without slab/open pit
- ☐ Composting toilet
- ☐ Bucket
- ☐ Hanging toilet/hanging latrine
- ☐ No facilities or bush or field
- ☐ Other (specify)

Q7 **Do you share this facility with other households?**

- ☐ Yes
- ☐ No
- ☐ Don't know

Q8 **How many households use this toilet facility?** ☐

Q8A **How many other households share this toilet?** ☐

Q8B **Can any member of the public use this toilet?**

- ☐ Yes
- ☐ No
- ☐ Don't know

Q9 **The last time (name youngest child) passed stools, what was done to dispose of the stools?**

- ☐ Child used toilet/latrine
- ☐ Put/rinsed into toilet/latrine
- ☐ Put/rinsed into drain or ditch
- ☐ Thrown into garbage
- ☐ Buried
- ☐ Left in open
- ☐ Other (specify) _______________________________
- ☐ Don't know

Appendix B: Water Quality Data Sheet

BWF Water Sanitation Survey of FOTO Project in Lower Nyakach, Kenya - July 2015

Residence Geocode: UTM

Water Source(s) Geocodes: UTM

VAF Name

VAF #

Office use only

Home Vessel (SWS)

Test for *E. coli*

10 mL Colilert Tube

Date Set | Time Set | Date Read | Time Read

RESULTS

θ / + θ / + θ / +

Petrifilm

Date Set | Time Set | Date Read | Time Read

Results

# of Blue Colonies

Test for Chlorine Residual

Date | Time

Results

Free Chlorine

Affix test strip

UTM Geocode - HWTS

Source Water

Test for *E. coli*

10 mL Colilert Tube

Date Set | Time Set | Date Read | Time Read

RESULTS

θ / + θ / + θ / +

Petrifilm

Date Set | Time Set | Date Read | Time Read

Results

# of Blue Colonies

Test for Chlorine Residual

Date | Time

Results

Free Chlorine

Affix test strip

UTM Geocode - Source

Appendix C: Instructions for Water Quality Tests

Residence Survey Permission

Before any data is to be collected, survey participant must give informed consent and sign the consent form

Coliform Test Procedures

Colilert tube

1	Collect water sample into sterile WhirlPak from the safe water storage unit or source water.
2	Using sterile pipette, aseptically transfer 10 mL of sample to Colilert tube.
3	Invert tube several times until Colilert media has dissolved.
4	Body incubate tube for 18-24 hours.
5	Record results with a positive (+) or negative (0) mark to corresponding color and fluorescence.
6	Record date and time when sample was set and read.
7	Label tube with UTM Geocode.
8	Deliver sample tubes to FOTO office for photographic documentation.

Petrifilm

1	Remove Petrifilm from foil package and reseal package with provided masking tape.
2	Label Petrifilm with sample date and time, VAF #, and the UTM Geocode of the sample location.
3	Using sterile pipette, aseptically transfer 1 mL of sample to Petrifilm.
4	Use plastic spreader and allow film to gel.
5	Package corresponding source and home vessel Petrifilms between provided cardboard
6	Body incubate tube for 18-24 hours.
7	Count typical colonies (blue colonies with gas production) and record number in result box.
8	Affix used Petrifilm to this sheet.

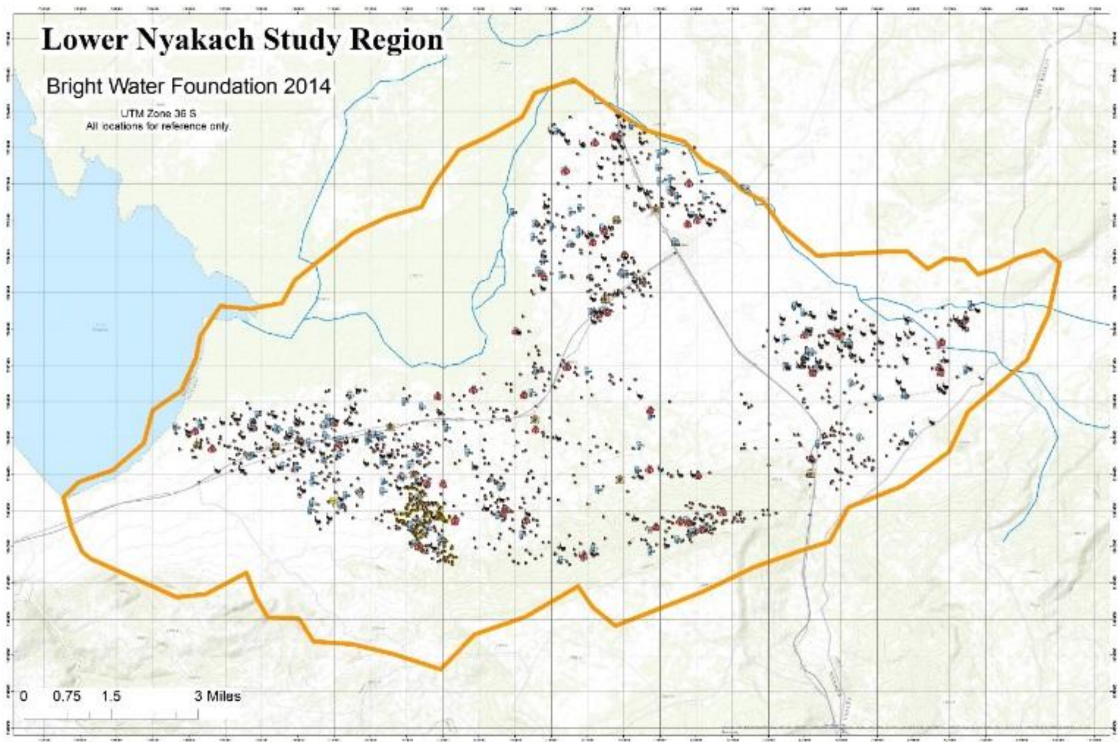
Chlorine Test Procedures

1	Collect sample into a sterile WhirlPak from the safe water storage unit.
2	Aliquot samples for Colilert Tube (10 mL) and Petrifilm (1mL) before testing for chlorine residual.
3	Remove chlorine test strip from package
4	Dip one test strip into WhirlPak water sample with a constant, gentle back and forth motion for **20 seconds**.
5	Remove the strip and shake once, briskly, to remove excess sample.
6	**Wait 20 seconds**, then view through the apertures to match with closest color for Free Chlorine with color chart located on reagent bottle.
7	Complete color matching **within 1 minute.**
8	After test strip dries, label the **geocode** for the residence or source water and affix strip to appropriate place on the data sheet.

Affix Petrifilm from Home Water Storage

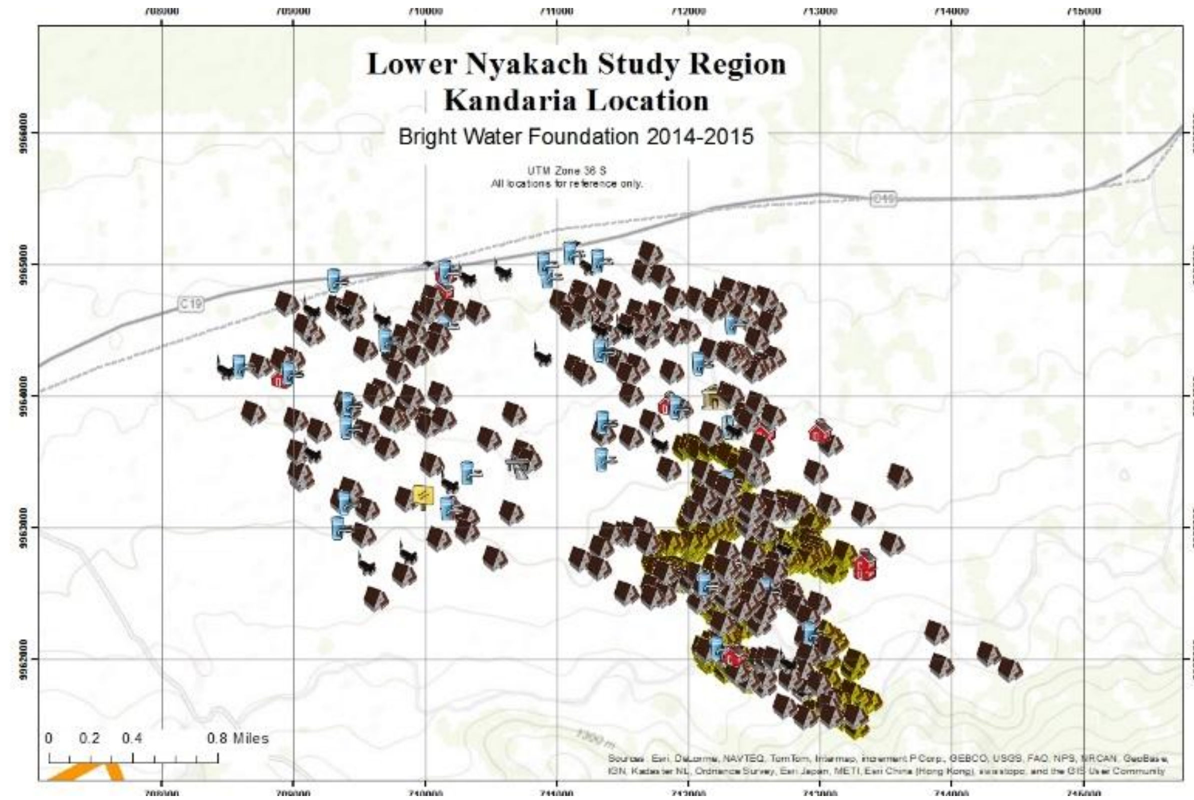
Affix Petrifilm from Source Water here

Appendix D: GIS Map of Lower Nyakach



Above: Map of Lower Nyakach Sampling Locations

Appendix E: GIS Map Sample Showing Homes in Relation to Source Water



Above: Map of Lower Nyakach Sampling Locations, Kandaria Source Water

Appendix F: GIS Map of Lower Nyakach Sampling Locations – Kandaria Data

symbol	description	NamingCode
Drinking Water	borehole - Josana	KNLN07 36S9962094712235
Drinking Water	borehole water for sale	KNLN07 36S9964951710169
Drinking Water	Harambee Borehole	KNLN07 36S9964917710948
Drinking Water	Harambee water point	KNLN07 36S9965094711119
Drinking Water	Kibuon pond	KNLN07 36S9964564712342
Drinking Water	Kojunga Water Project (piped water for sale)	KNLN07 36S9963772712326
Drinking Water	Pond	KNLN07 36S9964347711366
Drinking Water	Pump borehole	KNLN07 36S9963361712313
Drinking Water	Pump borehole	KNLN07 36S9964258712096
Drinking Water	Pump borehole	KNLN07 36S9963925711920
Drinking Water	Pump borehole	KNLN07 36S9963525711363
Drinking Water	pump borehole	KNLN07 36S9963426710337
Drinking Water	pump borehole	KNLN07 36S9963148710184
Drinking Water	pump borehole	KNLN07 36S9963944709432
Drinking Water	Pump borehole - Konyuro Market	KNLN07 36S9964885709322
Drinking Water	Pump borehole at Burkamwana Primary School	KNLN07 36S9964179708979
Drinking Water	Ragen Borehole	KNLN07 36S9964539710162
Drinking Water	seasonal pond	KNLN07 36S9962535712606
Drinking Water	seasonal pond	KNLN07 36S9962576712141
Drinking Water	Seasonal pond	KNLN07 36S9962755712306
Drinking Water	Seasonal Pond	KNLN07 36S9963806711371
Drinking Water	Seasonal pond	KNLN07 36S9964360711347
Drinking Water	Seasonal Pond	KNLN07 36S9965035711335
Drinking Water	Seasonal Pond	KNLN07 36S9963007709358
Drinking Water	Seasonal Pond	KNLN07 36S9963198709406
Drinking Water	Seasonal Pond	KNLN07 36S9963770709419
Drinking Water	Seasonal Pond	KNLN07 36S9964431709715
Drinking Water	seasonal pond	KNLN07 36S9964235708602
Drinking Water	Seasonal Pond - Kagok	KNLN07 36S9962203712943
Drinking Water	Well - at private residence	KNLN07 36S9965012710923

Appendix G: Certificate of Completion Protecting Human Research Participants

Certificate of Completion

The National Institutes of Health (NIH) Office of Extramural Research certifies that **Richard Blodgett** successfully completed the NIH Web-based training course "Protecting Human Research Participants".

Date of completion: 06/26/2011

Certification Number: 708783