Identifying Factors that Influence the Sustainability of a Gravity-Fed Water System in Rural Haiti

by

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Abstract

Background: The sustainability of water supply systems in rural, low resource settings is imperative to address as approximately 25% of water systems fail within four years of installation. Due to a long history of political instability, government corruption, countless natural disasters, and extreme levels of poverty, Haiti has faced myriad challenges associated with adequate water, sanitation, and hygiene (WASH) infrastructure for decades. Haiti Health Initiative (HHI) is a grassroots organization that has been present in the community of Timo, Haiti for 10 years. HHI worked with the community to expand a gravity-fed water system, now serving over 1,000 residents in the region. However, there were growing concerns regarding the sustainability of the water system expressed by both community members and the organization regarding the functionality and long-term sustainability of the water system.

Objectives: The purpose of this research was to understand the socio-technical factors that may influence the sustainability of a gravity-fed water system in Timo, Haiti by exploring the experience and perceptions of Timo residents. This research also evaluated the microbial quality of the water system in order to enrich the comprehensive understanding of the water system.

Methods: Qualitative description was used while following a community-based participatory research (CPBR) approach. Using purposeful sampling, 22 semi-structured interviews were conducted with adult residents of the community who had experience with the water system. Interviews were conducted in Creole by a Haitian research assistant, digitally recorded, and simultaneously translated and transcribed in English.

To evaluate microbial water quality, Aquagenx CBT ® *E. coli* MPN Kits were used to test three water points from each of the five reservoirs. Tests were taken at the beginning, middle, and end of the system to determine the level of faecal pollution that occurred throughout the reservoir lines to community standpipes.

Results: Three main categories emerged from the interviews; Perceived improved quality of life due to the system, initiative to maintain the system, and lack of community cohesion. These are all factors that are perceived to impact the overall sustainability of the system. Improved quality of life and community initiative appeared to not impact one another, but both influence initiative to maintain, which ultimately impacts sustainability. Regarding microbial testing, only 27% of water points tested were concluded as Safe based on the World Health Organization's Guidelines on Drinking Water Quality.

Conclusions: Sustainable delivery of safe drinking water in Timo is more a function of the human system than the technical, yet faecal pollution needs improved technical control. Ongoing maintenance and initiatives to preserve the safe function of the system are key to its success or failure. Based on the findings, a report for the organization and community has been created with recommendations to improve the functionality and sustainability of the system. This research will also inform those working on creating more context-specific water supply systems in rural/remote regions globally.

Preface

This is an original work by Heather Nixdorff. Ethics approval was received from the University of Alberta's Research Ethics Board under the study title: "Factors of Sustainability in a Gravity-Based Water System in Rural Haiti" No. Pro00079629 (March 29, 2018, renewal expired March 28, 2019). Ethics approval was also received by the Haitian Ministry of Health under the study title: Facteurs de la durabilité d'un système hydrique gravitaire en milleu rural en Haiti" Ref: 1718-33 on May 3, 2018. This research was also approved by Haiti Health Initiative, the partnering organization for this project.

Chapter 3 of this thesis will be submitted as Nixdorff, H., Ashbolt, N. J., Storey, K., Martial, M. A., Cole, G., Evens, R., Petit, M. (2020). Identifying factors that influence the sustainability of a gravity-fed water system in rural Haiti. *Journal of Water, Sanitation, and Hygiene for Development.*

Dedication

This thesis is dedicated to the people of Timo. Mesi.

Acknowledgements

This thesis was made possible from the support and encouragement from so many people. Though it is only my name on the front of this thesis, so many names deserve to be included.

Supervisor Dr. Nicholas Ashbolt, thank-you for allowing me to pursue this topic as my thesis project, encouraging my independence and supporting me throughout. Dr. Kate Storey, thank-you for your guidance and patience in helping me wade through qualitative research while being a warm and kind presence.

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Evens Roberts, thank you for being my person while in Timo. You were an outstanding Research Assistant. More than that, you helped me feel welcomed and comfortable in a home far away from my own.

To the people of Timo: Thank-you for sharing your community, stories, and lives with me. Your hospitality and humour will not be forgotten. Thank-you for making me feel like family and inviting me into your homes. Harvesting and shucking beans, braiding/shaving hair, playing hopscotch, “ti-boul”, and listening to the boys sing will remain some of my favourite memories.

To my parents and family: thank-you for your unwavering support. Mama Nix, pursuing this thesis project independently would have not been possible without your support and encouragement. I feel that I will never be able to properly articulate how much your encouragement of me pursuing my passions means to me.

To my friends within and outside of the School of Public Health, thank you for lending an ear or shoulder when I needed it. My time in the School of Public Health included many hills and valleys, but I am grateful for each experience.

Happy days.

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List of Acronyms

CAEPA: Comites d'Approvisionnement en Eau potable et d'Assainissement

CBPR: Community-based participatory research

CBT: Compartment bag test

CFU: Colony forming units

ExPEC: Extraintestinal pathogenic

EPEC: Enteropathogenic

GPS: Global positioning system

HHI: Haiti Health Initiative

IBNET: International Benchmarking Network for Water and Sanitation

MDG: Millennium Development Goals

MPN: Most Probable Number

NGO: Non-governmental organization

DINEPA: Direction Nationale de l'Eau

O&M: Operation & maintenance

WASH: Water, sanitation, and hygiene

GFWS: Gravity-fed water system

PWS: Piped water scheme

PCS: Post-construction support

PVC: Polyvinyl chlorine

WSP: Water safety plan

Chapter 1: Introduction and Background

Access to clean water is recognized as a basic human right and fundamental for the realization of other human rights (Barnes, 2009; United Nations, 2014). However, approximately 2.1 billion people do not have access to safe drinking water (UNICEF, 2017), and eight out of ten people who are without clean drinking water live in rural areas (World Bank, 2017c). There have been many efforts and initiatives that have focused on increasing access to clean drinking water, including the Millennium Development Goals, Sustainable Development Goals, and United Nation's Water Decades. Thanks to these initiatives and many others, the number of people living without improved drinking water was halved between 1990 and 2010 (UNICEF, 2011). Unfortunately, many of these projects and initiatives lacked appropriate planning, implementation, and post-construction support, ultimately leading to system failure. Globally, approximately 15 percent of water points fail within one year, and 25 percent are non-functional in four years (Banks & Furey, 2016). The water sector in Haiti faces myriad challenges to sustained water services - 65% of urban and 48% of rural households have access to improved water sources (Rayner et al., 2016). Such low rates are due in part to political instability and many natural disasters. These natural disasters have severely impeded development measures, and many organizations that have provided services to Haiti have been short-term or relief based with little collaboration with the government (Widmer et al., 2014). Exploring the experience of rural Haitian residents with water services is recommended in order to create a more collaborative approach to sustainable water supply (Gelting et al., 2013; World Bank, 2017a). Therefore, this thesis focused on exploring the experience of residents in a rural Haitian village using a gravity-based water system. Exploring their experiences enabled an understanding of the factors that may be influencing the sustainability of the water system.

The second part of this thesis focused on creating a baseline understanding of the microbial water quality of a gravity-fed water system in a rural Haitian village. Faecally-contaminated drinking water transmits a range of pathogens, including hepatitis A virus, pathogenic *Escherichia coli (E. coli)*, *Vibrio cholerae, Salmonella enterica* subtype typhi and *Cryptosporidium* spp. (Cumming et al., 2019). Approximately 500,000 deaths occur each year due to diarrheal illness caused by contaminated water (World Health Organization, 2018). The health burden resulting from contaminated water can have detrimental effects on the well-being of individuals and the larger community, impacting sustainable development, economic stability, and food security (United Nations, 2018). Understanding the microbial water quality aids in creating a more comprehensive approach to assessing the impact and functionality of a water system. Furthermore, organizations working in and with communities have an ethical responsibility to ensure that the infrastructure or services that they provide are an improvement on the status of water quality used by communities before the intervention.

History of community-management in water systems

Prior to the 1980's, state governments were generally responsible for water supply in rural, developing regions. However, acknowledging many governments' inability to reliably supply safe water, there was a shift towards a de-centralization and community-management model (Carter et al., 1999; Harvey & Reed, 2006; Kelly et al., 2017). The community-management model was appealing to non-governmental organizations (NGO) working in these countries as this allowed them to create projects in communities and depart shortly thereafter, placing the responsibility of managing the water system onto the community (Harvey et al., 2006). However, in successful community-management models, there is post-construction support (PSC) in the form of technical or financial assistance, either provided by an NGO or private entity (Kelly et al., 2017).

It is imperative to differentiate between community-management and community participation in water systems and their sustained functioning. Firstly, community participation is a consultative process. The community is provided with adequate information in order to make informed decisions regarding the aspects of the water system, rather than it being decided for them by the external organization. These decisions include technology type, system layout, tariff structure, and operation and maintenance (O&M) (Harvey et al., 2006). Gleitsmann et al. (2007) describe this as the 'platform approach' as it utilizes the assets and knowledge of all stakeholders (community, external organizations) in decision making. Breslin (2003) explains that the foundational aspect of a demand-responsive approach is communities taking greater responsibility for the decisions that affect their lives, and that issues such as operation and maintenance, management structure, and tariffs are not imposed on by external organizations or outside stakeholders. They emphasize that decisions must reflect what the community thinks they can manage and sustain in their own context; not what external stakeholders think the community can manage and sustain. In many cases, communities have decided to have less involvement in the O&M of the system if they feel they do not have the capacity or enough resources.

Secondly, community management is merely a type of community participation, as it should be the community's decision to take on more responsibilities or to request increased external support (Harvey et al., 2006). In community-managed systems, much of the O&M is the responsibility of the community. If an external stakeholder places the responsibility solely on the community and deems it community management, this system is likely to fail; community-management connotates a legal responsibility of a water supply, but does not imply a sense of accountability or initiative to maintain (Harvey et al., 2006).

Sustaining water systems in rural & remote communities

Sustainability of water services has been defined as “whether or not something continues to work over time” (Abrams, 1998, p. 5). For this thesis, sustainability of the water system refers to the “ability of [water] services to continue to provide recipients with the intended human health and lifestyle benefits without a significant adverse effect on other people, the environment, or other services” (Barnes, 2009, p. 79). Carter et al. (1999, p. 7) add that the test of sustainability regarding water systems is that “water continues to be abstracted at the same rate and quality as when the supply system was designed.”

There are many studies that have identified various factors which support sustainability of water systems (Barnes, 2009; Montgomery et al., 2009). Table 2 lists common sustainability factors and examples of each. Is it important to note that even if each of these factors are present, it does not guarantee a water system will be sustainable. This is referred to as the clockwork myth, and may create false expectations for both organizations and communities (Abrams, 1998).

Table 1. Examples of sustainability factors in water supply systems.

Factors for Sustainability	**Example(s)**
Economic	The cost of implementing or maintaining the system
Social	Acceptance/adoption of water system, ownership/accountability in the community, perceived taste/odor of water, presence of women in water committee
Environmental	Effect on the surrounding environment to provide ecosystem services
Technical	Technology choice and local availability of parts and their maintenance
Human Health	Impact on human sickness and general wellbeing
Political	Presence of external support (NGO, government, etc.). Political/socio-economical

When a water system fails, it may be due to a lack of oversight regarding a sustainability factor (Table 1). For example, communities may not be convinced about the importance of the intervention and therefore not see purpose in it, the cost to maintain the system is higher than what the community has capacity for, or those who were trained and skilled in maintaining the system leave the community. One of the original frameworks of sustainability by Carter et al. (1999) (Figure 1) describes that if any part of the sustainability chain is not met, the sustainability of the system will be compromised.

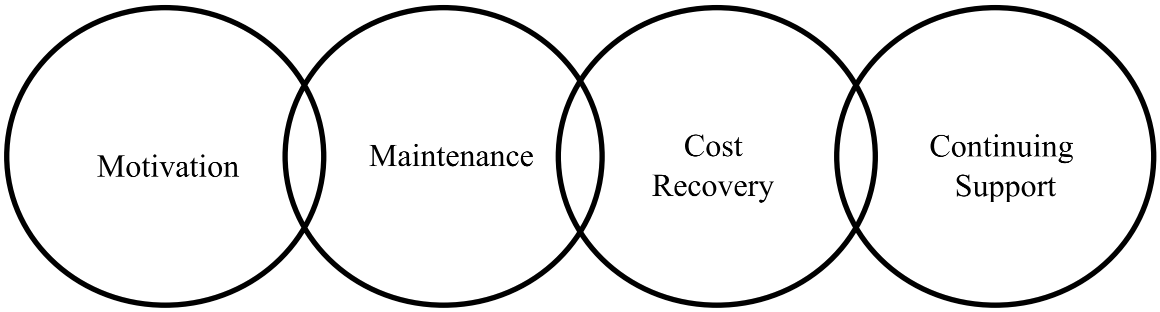

Figure 1. The Sustainability Chain as proposed by Carter et al. (1999).

In a systematic review of 174 successful community-management models of rural water supply systems in the past 30 years, long-term external support was essential to sustainability. This included financial assistance and support for technical and managerial aspects (Hutchings et al., 2015). Collective initiative, strong leadership, and institutional transparency were listed as internal characteristics of the community that were crucial to success. The authors also found that the success of community-managed water systems are directly impacted by the socio-economic well-being of the society or nation that it is situated in, including urban drift, government structure, education and health systems, and modern communication. Abrams (1998, p. 2) emphasized that "no community is an island" and cannot function on its own, independent of the rest of society. Social flux, urban drift, government structure, education and health systems, and modern communication all impact development and sustainability. Hutchings et al. (2015) elaborates on this notion, hypothesizing that there may be a relationship between success of a water system and the socio-economic status and stability of the society. Finally, although it may appear unrealistic or unfair to expect communities in low resource settings to pay for their water systems, payment for operation and maintenance is a common factor in sustainable community water systems (Montgomery et al., 2009; Schweitzer & Mihelcic, 2012; Whittington et al., 1990).

In recent years, there has been a push for establishing a universal framework for sustainability in rural water systems to create a more cohesive and uniform monitoring system. The International Benchmarking Network for Water and Sanitation (IBNET) has a set of indicators for urban water supply, however these indicators do not necessarily transfer to rural supply. The lack of transfer of indicators to rural supply is partly due to the varying types and levels of technical complexity. Service provision may come from a variety of sources, whereas in urban areas, there is an assumption that there is an established utility-like provider (World Bank, 2017c). In 2017, the World Bank proposed 24 indicators to be used by countries in rural settings. This framework includes indicators on service level, functionality, sustainability (governance, O&M performance, financial management, environmental and resource management, customer relations), and service authority presence. A set of universal indicators is important for monitoring and comparison, however this framework does not address the internal characteristics of a community listed by Hutchings et al. (2015) that are imperative to sustainability.

Haiti

Occupying approximately one-third of the island of Hispaniola that it shares with the Dominican Republic, Haiti has a population of 10.8 million people (World Bank, 2017b). Haiti had the first and only successful slave revolt in history; however, the impact of the slave trade on the country and political instability that followed independence in 1804 has left Haiti in a severe state of poverty (Gelting et al., 2013). Haiti is the poorest country in the Western Hemisphere, with over six million people living on less than $2.50 USD per day (World Bank, 2019).

The country is also extremely vulnerable to natural disasters, which consistently challenge any development measures. The earthquake in 2010 took the lives of over 200,000 people, displaced over 2 million (Center for Disease Control, 2014; Dowell et al., 2011), and destroyed building, road, and communications infrastructure (including the Haitian Ministry of Public Health and Population) (Dowell et al., 2011). Tent cities and collapsed buildings are still found throughout the country – evidence that the impact is still present nine years later (University of Fondwa, 2019). A second earthquake in 2010 followed by a cholera outbreak that took the lives of over 9,000, in addition to Hurricane Matthew in 2016 that continued to exacerbate devastation across the country.

Water supply infrastructure and governance in rural Haiti

Direction Nationale de l’Eau Potable et le l’Assainissement (DINEPA) is the national water service authority in Haiti. Figure 2 illustrates the governing levels that are responsible for water services in Haiti. The water sector law (Loi Cadre) states that community-based management is the primary management model for rural areas, and that the Comites d’Approvisionnement en Eau Potable et d’Assainissement (CAEPA) are responsible for management, maintenance, and operation activities (World Bank, 2017a).

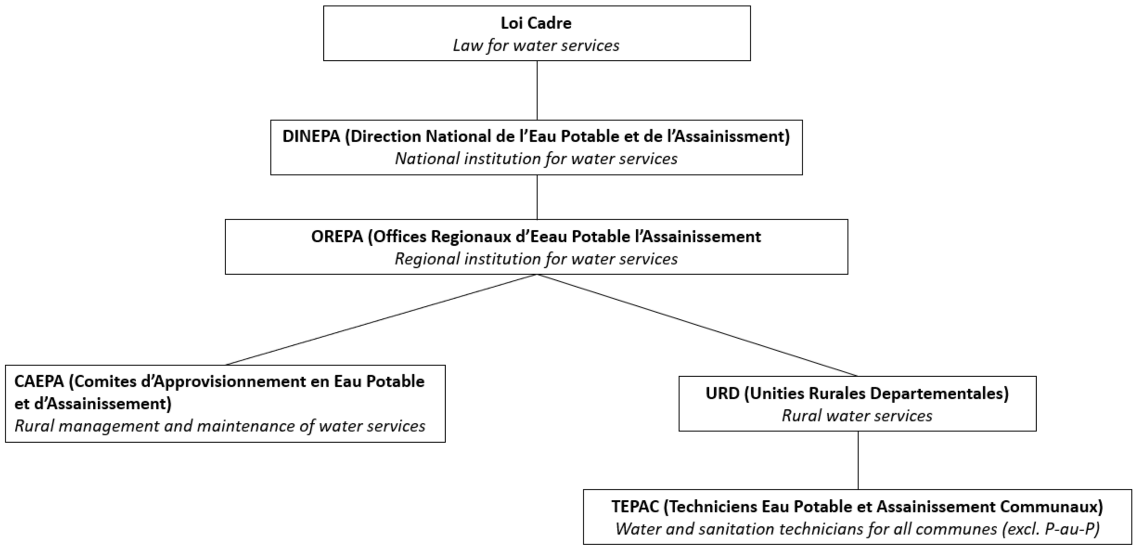

Figure 2. Institutional responsibilities for water services in Haiti summarized from (World Bank, 2017a).

Water system sustainability in rural Haiti

Haiti has the lowest coverage of improved (protected source) water access in the Americas - 65% of urban and 48% of rural households have access to improved water sources (Rayner et al., 2016). Unfortunately, despite millions of dollars and hundreds of volunteer groups and organizations implementing many water interventions, those who live in Haiti continue to struggle with consuming contaminated drinking water. This is intensified for rural residents, as many interventions have been focused on urban centers. Though the exact amount of financial aid is unavailable, USAID alone contributed $4.4 in billion dollars in response to the 2010 cholera outbreak for immediate response and following development measures (Center for Economic and Policy Research, 2018). Regarding the water sector specifically, a continued absence of development is partially due to the lack of coordination between DINEPA and those providing these interventions in addition to a lack of long-term planning for these interventions in the communities they were meant to serve. In response to the 2010 earthquake and subsequent cholera outbreak, over 100 non-governmental organizations and faith-based groups entered the country to assist in providing safe drinking water and sanitation to communities (Gelting et al., 2013). Water point construction in the Léogane and Gressier region increased from three to 361 water points during the immediate response period, many focussing on short-term interventions to mediate the spread of cholera (Widmer et al., 2014). In addition, there was little oversight and collaboration between many of the intervention implementers and DINEPA (Gelting et al., 2013). Regarding management strategies, 68% of the 361 water points did not have a management strategy in place, 98% did not require payment, and 45% reportedly had a pump keeper responsible for pump access. As the threat of cholera decreased, many of the organizations and groups departed Haiti or significantly scaled-down their work. What was left was many water supply systems that lacked the proper planning and implementation to create sustainable water systems for the communities to continue independently. Furthermore, in a study evaluating the sustainability and functionality of water systems in Haiti, Rayner et al. (2016) evaluated 79 tablet-based chlorinators for gravity-fed water systems installed in 2012 and 2013. They reported that although 83% were functional, only 56% of sites had enough water pressure to operate, and none of the sites had any chlorine tablet access. Lack of accountability, tablet access, and management systems were identified as reasons why the chlorinators were not sustained.

Important steps have been taken to create a more cohesive water governance structure in Haiti, though there are still many gaps. The World Bank (2017a) completed a Sustainability Assessment at the sector level for rural water supply services in 2017 (Table 2). Haiti scored weak or moderate in every category. Many of the challenges were related to governmental structure and legal power of the water supply sector. In addition to these challenges, community-based organizations must register with DINEPA if they want to work in a community and manage a PWS (piped water scheme). However, there remains confusion around the specific roles of CAEPAs, and only 39% of the known PWS are registered as a CAEPA (World Bank, 2017a). Furthermore, there is reported lack of coordination between the sectors in addition to a lack of government attention and funding being allocated to rural areas, creating a higher reliance on donor funding (World Bank, 2017a).

The lack of coordination within government and between organizations in the WASH sector has created a very challenging scenario of failing infrastructure, confusion, and distrust. Resistance to pay for water is common in Haiti due in part to lack of transparency and trust in those responsible for O&M of the system in the community, and lack of trust in DINEPA (Rayner et al., 2016; World Bank, 2017a). In addition to recommendations for governance, recommendations related specifically to communities included further understanding of community's willingness to pay, identifying appropriate services and management models, investigating community's capacity for management of infrastructure, and increasing coordination of donors and organizations working in the country.

Table 2. Summary of Sustainability Assessment adapted from World Bank (2017).

Criteria	Score	Challenges
Institutional capacity for rural water service delivery	Moderate	- Weak planning capacity and coordination - URD's and TEPAC's do not have legal basis - Weak technical and financial management for service providers
Financing for rural water service delivery	Weak	- Almost entirely dependant on international transfers - No mechanisms for harmonization among funders - Willingness to pay is very low (lack of trust) - No tariff policy
Asset management for rural water service delivery	Weak	- Over 40% of PWS do not have daily service - Ownership of all water assets by DINEPA is not well known - Service authorities are not equipped nor have asset inventory - Technical guide is not written in Creole
Water resource management and security	Weak	- Outdated/incomplete water resource information - Population increase and climate change threaten water resources - No regulation of water abstraction - No integrated resource management from institutions responsible (initiated locally)
Monitoring and regulation of rural water service delivery	Moderate	- No national monitoring framework - No inventory of water points - No national standards for water quality nor monitoring - Free water treatment equipment (Hypo-Klor 24) not well distributed in rural areas - Water quality control system (SIS-KLOR) is threatened by lack of funds and buy in by DINEPA

Microbial testing and sustainability

Relating back to the definition of sustainability as proposed by Barnes (2009), a primary aspect of a sustainable water system is its ability to provide human health benefits to recipients. Evaluating (and managing) the microbial water quality is key in decreasing the incidence of illness caused by contaminated drinking water (World Health Organization, 2017).

There is a wide spectrum of waterborne pathogens (bacteria, viruses, protozoa, helminths) that may be found in drinking water and pose a threat to human health; however, it is impractical to test for each pathogen on a routine basis. Using faecal indicator bacteria is the most practical means of monitoring drinking water quality (Ashbolt, 2015; Odonkor & Ampofo, 2013), as it can infer that other pathogens may be present and provide insight to drinking water quality (Ashbolt et al., 2001). Indicator bacteria are differentiated from process (surrogate) indicator bacteria and neither may provide an index for pathogen concentration, but are used to indicate the efficacy of a process/treatment and the likely presence of waterborne pathogens (World Health Organization, 2017).

Escherichia coli (E. coli) is a common bacterium present in excreta, which along with *Citrobacter*, *Klebsiella* and *Enterobacter* represent the major members referred to as total coliforms, used to assess water quality and treatment performance respectively (World Health Organization, 2017). *E. coli* is a Gram-negative, facultative anaerobic, non-sporulating bacterium that is indigenous to the lower intestine of warm-blooded animals, but also present in cold-blooded animals and the environment (Ashbolt, 2015) .There are many types of *E. coli* that are part of the human gut microbiome; most are harmless or even beneficial, however some extraintestinal pathogenic (ExPEC) and enteropathogenic (EPEC) strains can cause serious illness or death in humans (Nowrouzian et al., 2019). Non-pathogenic *E. coli* is used as an indicator organism due to its prevalence in human faeces and the availability of more accurate and affordable field tests in comparison to other indicator bacteria. World Health Organization Drinking Water Quality Guidelines (World Health Organization, 2017) has set guidelines for drinking water quality and the recommended amount of *E. coli* is non-detected in 100mL samples. Testing for the presence of *E. coli* indicates likely faecal contamination, not necessarily that human pathogens are present in the sample; however it does indicate the likelihood of faecal pathogens that may pose a human health risk such as *Salmonella spp*. and Hepatitis A (Odonkor et al., 2013). This test is also not perfect; there is no biochemical marker to differentiate between pathogenic and non-pathogenic *E. coli*, which may create unnecessary alarm.

In addition, most *E. coli* do not survive for long outside of their host, requiring regular monitoring of samples that typically indicate recent faecal contamination. However, environmental *E. coli* may colonize water and soils in warm tropic regions (Ashbolt, 2015). A solution to *E. coli* being found in warm tropics is to follow-up with testing for another faecal indicator such as *Clostridium perfringens* (Ashbolt et al., 2001) or specific faecal source marker genes when resource allow such molecular methods and when there is a need to identify and control specific faecal sources (Li et al., 2019).

Other means for testing the efficacy of water treatment include the total coliform (TC) group within which *E. coli* is a member and the Hydrogen Sulfide (H_2S) test (for various clostridial bacteria, including *C. perfringens*). The TC method tests for the production of the enzyme β-galactosidase as a result of lactose fermentation. However, the test cannot specify the particular thermotolerant coliforms in the sample and includes thermotolerant non-faecal coliform bacteria (Odonkor et al., 2013; World Health Organization, 2017). The H_2S test, also known as the paper-strip method was originally described by Malta et al. (1982) after it was observed that hydrogen sulphide is produced by sulphite-reducing *Clostridium* spp. The H_2S test indicates a positive result in the production of a black precipitate as a result of sulfide reacting with the iron in the medium (Sobsey & Pfaender, 2002). The H_2S test is an acceptable test for general faecal contamination, however it may also detect non-faecal clostridia present in groundwaters (Roser et al., 2005). Other drawbacks to the H_2S method are that the test reacts to very small amounts of sulfide that may be formed from (abiotic) chemical reactions, H_2S can be found in the environment (organic, non-faecal, waste), and there are other metal salts that may produce H_2S (Sobsey et al., 2002).

Three common approaches are used for measuring faecal indicators are*:* the presence/absence test (P/A), most probable number (MPN), and membrane filtration method. P/A testing is qualitative, hence provides no quantitative or concentration information. The H_2S test is an example of using P/A. The MPN test, originally developed by McGrady in 1915 (Sutton, 2010), uses an assumed Poisson distribution of target bacteria to statistical estimate the concentration of bacteria in a sample. A water sample is typically separated into different wells or compartments and MPN units are statistically estimated using the number of positive samples (Blodgett, 2010). The membrane filtration method captures bacteria on a filter that is then incubated on a selective/diagnostic agar plate. Single cells or clumps of cells for colonies will grow if the bacteria is present, with the result reported as the number of colony forming units (CFU) (Bartram & Pedley, 1996).

Microbial testing in low resource settings

Laboratory testing methods for faecal contaminants - such as the ones described above - typically requires a suite of equipment, materials, and trained personnel. In the case of rural regions or low resource settings, a laboratory to complete the testing would not be readily available. A testing facility may be hours away on challenging roads, so the requirement for rapid transport and appropriate preservation (testing within 6-8h) results in high costs (MacDonald et al., 2005; Sobsey et al., 2002). Fortunately, in the last 20 years, field testing kits have been created to provide accurate results in the field with little required user skill, material or equipment. There are many field-testing kits in circulation today that can be used in low resource settings including those sold by La Motte, Fischer Scientific, IDEXX, and Aquagenx. Though most of these companies' kits resemble one another in a variety of ways, Aquagenx® Compartment Bag Test (CBT) was chosen for this study primarily because no electricity or incubator is required.

The Aquagenx® CBT was developed by Dr. Mark D. Sobsey and his team from the Gilling School of Global Public Health at the University of North Carolina Chapel Hill. The test was created to be simple to use, easy to interpret, and accessible to individuals or communities with little to no training required. It does not require any lab equipment or electricity, has a long shelf-life, and does not require cold preservation. The tests can be incubated in ambient and variable temperatures above 25 degrees Celsius, yielding results in 24-48 hours (Aquagenx, 2019b). It has been validated and proven comparable to standard methods such as membrane filtration (Stauber et al., 2014; Wang et al., 2017) and the IDEXX Colilert® MPN method (Brooks et al., 2017; Murcott et al., 2015).

Aquagenx® currently carries two tests, the CBT *E. coli* + Total Coliforms Kit, and the CBT H2S Kit. The CBT *E. coli* Kit uses a β-glucuronidase substrate (X-Gluc) that when metabolized by *E. coli* in the sample, turns the water blue/green. If total coliforms are present, the fluorogenic galactoside substrate (MUGal) will be metabolized causing the sample to fluoresce blue under an ultraviolet light. The Aquagenx® H2S Kit tests for the presence of hydrogen sulfide-producing bacteria that turn the growth medium black (Aquagenx, 2019b). Both tests can be used to determine MPN or P/A. To test MPN, a 100 millilitre (mL) water sample is poured into five compartments of differing volumes of 10 mL, 30 mL, 56 mL, 3 mL, and 1 mL (Gronewold et al., 2017). The results are concluded by comparing any compartments with as little as a trace of blue or green color (Figure 3) with a chart based on the World Health Organization Guidelines for Drinking Water Quality 4th Edition (World Health Organization, 2017). Although no *E. coli* should be in 100 mL of water, numbers up to 20/100 mL may be tolerated as being intermediate but allowable risk depending on the setting the sample is taken in (Aquagenx, 2019b).

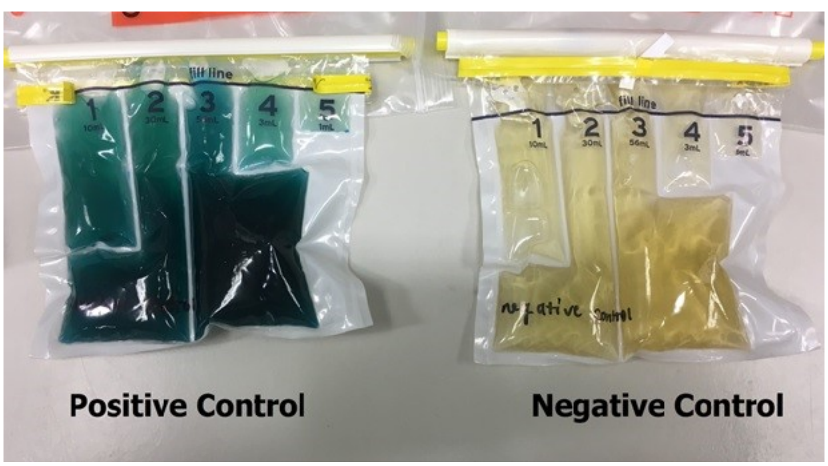

Figure 3. Aquagenx CBT Positive and Negative Control

Timo, Haiti

Located within the 10th Communal Section of Fond'Oies in Haiti's Western Department (Martial, 2019), the small community of Timo is situated in a mountainous valley of southern Haiti, 65 kilometers from its capital, Port-au-Prince (Figure 4a). The nearest city to Timo is Léogâne. Access to Timo is via a 3-kilometer hike through steep, narrow and rugged terrain off the main road that runs through Tom Gateau, the nearest town (Figure 4b). Due to its proximity to Léogâne, (the epicentre of the 2010 earthquake) infrastructure in Timo was destroyed, including parts of the water system (Figure 4c). The population of Timo is approximately 1,000. Residents of Timo exist on less than $1 U.S. per day and are among the poorest people in Haiti (Martial, 2019).

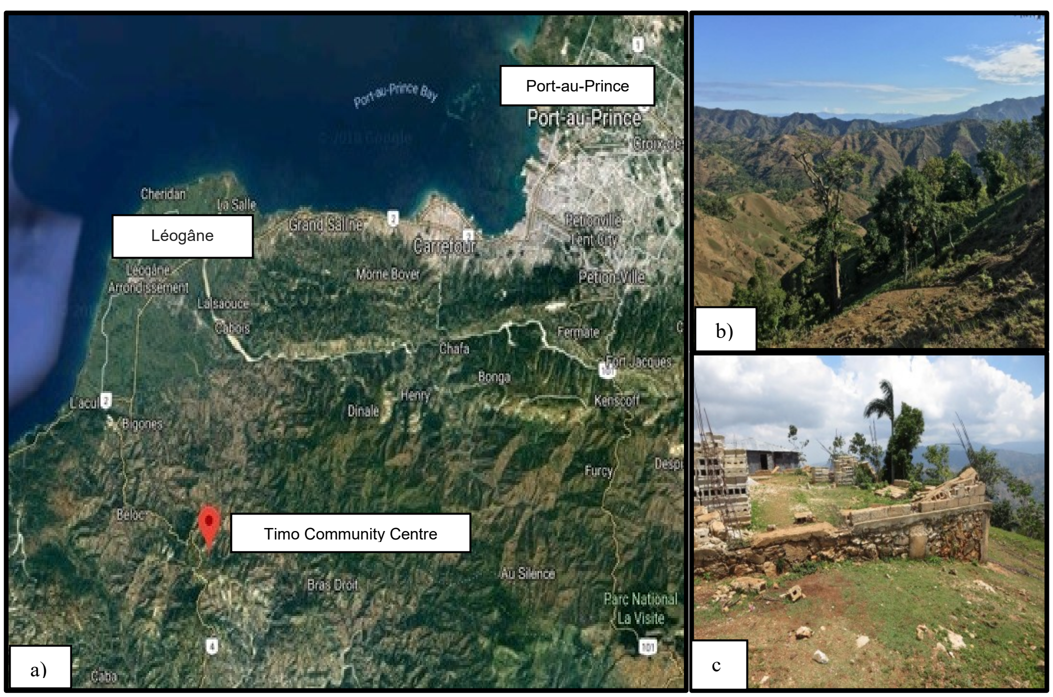

Figure 4. Location and landscape of Timo

Haiti Health Initiative

Haiti Health Initiative (HHI) is an NGO headquartered in Utah that has been present in the community of Timo since 2005. Every six months, a team primarily consisting of medical and dental professionals travel to Timo to provide education and clinical care. HHI also has community projects in education, nutrition, and agriculture. In 2008, HHI expanded a pre-existing gravity-fed water system that was originally built in 1994 by a local organization. At present, there are five reservoirs leading to 53 taps, used by over 1,000 people. Taps located near the public road are frequently used by those who are passing through the community.

Figure 5 depicts a simplified example of one reservoir system in Timo. A catchment constructed at a spring collects ground water that has been naturally filtered through the ground. The water collects at the reservoir and is distributed throughout the community via high-density polyethylene (HDPE) pipes. Since gravity is the force that is driving the water from source to stand-pipe tap, there is no external energy source required for distribution. In piped-distribution systems, the quality and safety of the pipe is critical in maintaining acceptable drinking water quality standards and avoiding contamination (Odonkor et al., 2013).

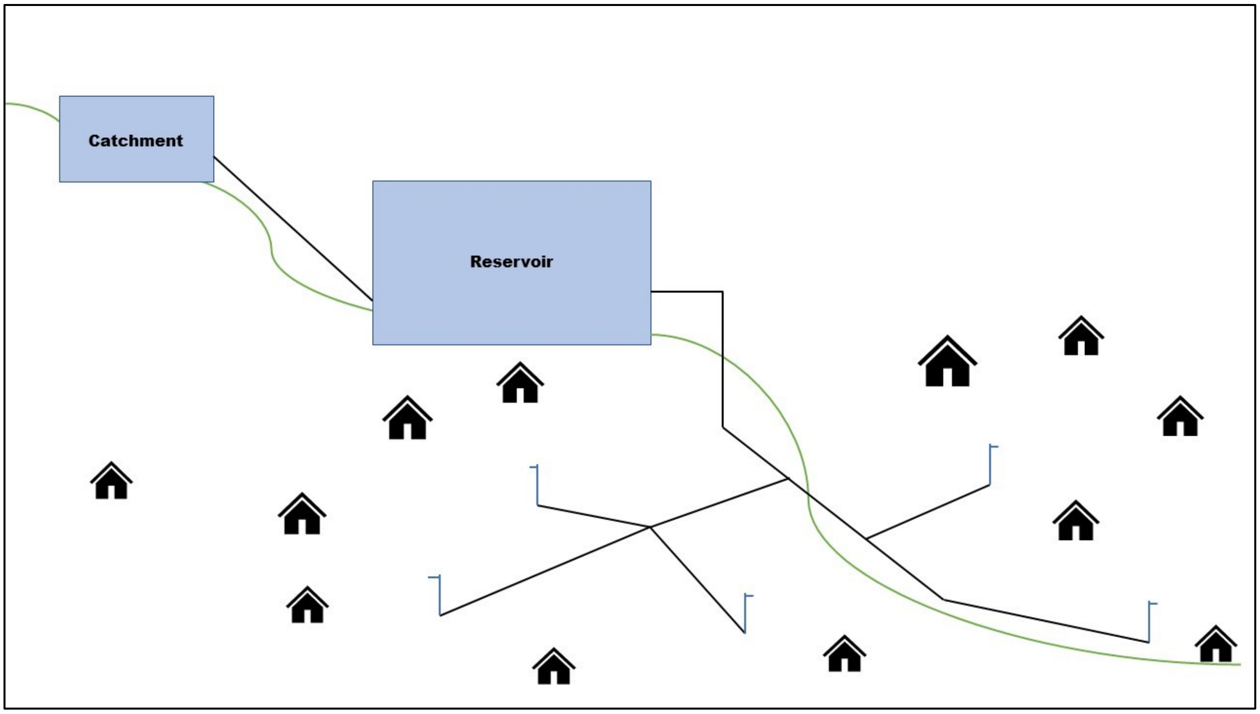

Figure 5. Example of catchment, reservoir, and taps in Timo, Haiti.

A water committee and water master consisting of residents was identified by the community and had already been established before HHI started working with the community. Through the years, some committee members have left the committee or moved away, however the structure has remained the same. Figure 6 illustrates the responsibility structure of the water system in Timo. There is one community liaison, one water master, and one primary committee member for each reservoir system. The committee is responsible for small fixes in the system as needed, but relies on HHI for tools, products, chlorine treatment, and assistance in addressing larger scale problems. This equipment and assistance are typically only available twice a year when HHI teams travel to Timo for the week-long clinics.

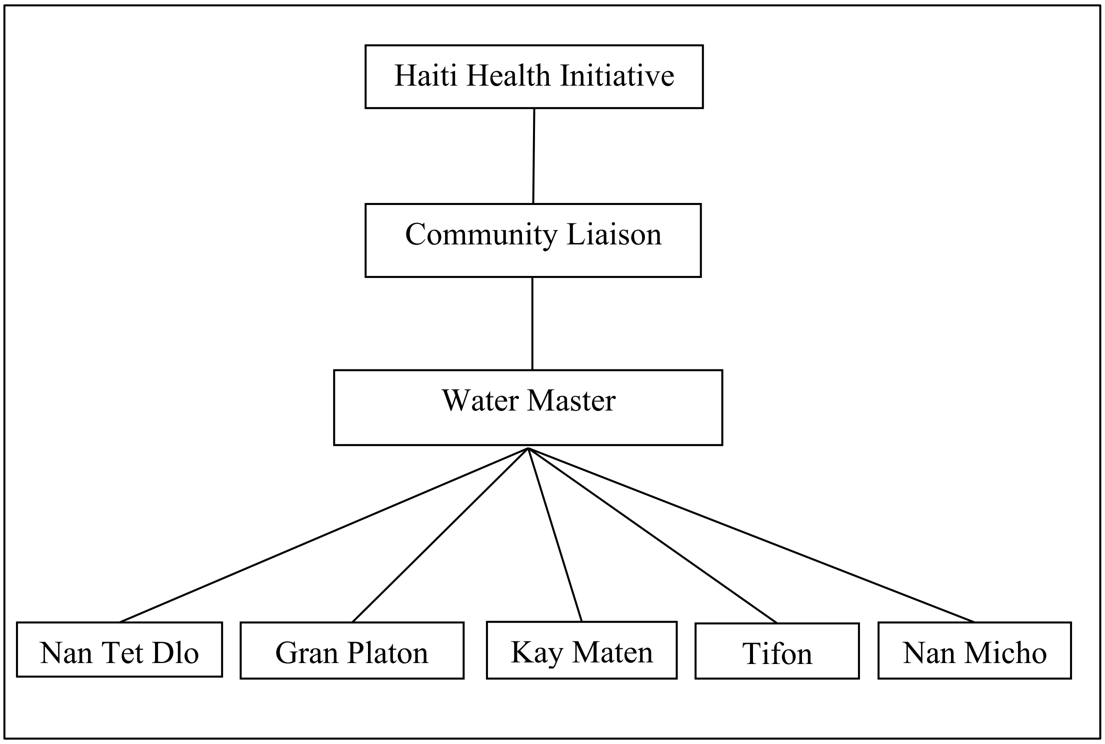

Figure 6. Water system management in Timo.

There have been growing concerns regarding the sustainability of the system, being described by HHI as “a house with no windows” (Petit, 2017). HHI is interested in installing an automatic chlorine dispenser as a means of centralized water treatment but would like to address management and sustainability concerns first. Furthermore, in April 2017 a functionality assessment was completed that included visiting each tap site and reservoir, noting its physical state and recording its location. The assessment revealed that some 72% of taps were functional and delivering water, and 50% needed repair. Of the 50% recorded as in need of repair, two standing posts were in such disrepair that they were laying on the ground. One tap was noted as in need of repair due to the amount of standing water under the tap due to poor drainage. At one of the reservoirs, the valve used to empty the tank was broken, and the reservoir had subsequently not been cleaned in three months. Furthermore, two catchment covers required immediate attention, as there was either wood acting as a cover, or a hole had formed in the center of the metal cover, posing an increased risk of faecal contamination from wildlife. This assessment provided further reasoning for the study to be completed. Additionally, as HHI has a long relationship with the Timo community, there was strong rationale for completing this research in Timo. There are very few studies focusing on water systems in Haiti, and apparently none that focus on the experience of those who use a rural water system. The geographical location of Timo also made this an ideal location as it is relatively isolated with clear boundaries.

Chapter 2: Research Objectives and Scope

Haiti has faced decades of political, economic, and social challenges that continue to impede development measures in the water sector (Gelting et al., 2013). Though many NGO's have provided aid in this area, a lack of collaboration and focus on long-term functionality has left many water systems in disrepair (Rayner et al., 2016). In addition to creating a more cohesive governance structure, community level approaches to addressing the water sector include engaging with rural communities. Exploring the experience of rural Haitians with water services would enable a more collaborative and context specific approach to creating sustainable water supplies (World Bank, 2017a). Secondly, long-term sustainability of community water supply systems requires ongoing assessment of water quality and functionality (Widmer et al., 2014).

Haiti Health Initiative, an organization working with the community of Timo, Haiti expressed concern regarding the sustainability of the gravity-based water system in the community. To gain a comprehensive understanding of the water system and aspects that may be influencing the sustainability, exploring the experience of the residents of Timo in addition to microbial water quality testing of the water system was desired.

Thus, the objectives of this thesis were to:

1) Explore the experience of residents using a gravity-fed water system in the rural community in Timo, Haiti (Chapter 3);
2) Determine what factors influenced the sustainability of the Timo gravity-fed water system and make recommendations for improvement (Chapter 3); and
3) Assess faecal contamination of the water system via quantification of *E. coli* (Chapter 4).

Chapter 3: Exploring the Experience of Residents Using a Gravity-Fed Water System in Rural Haiti

**Will be submitted to Journal of Water, Sanitation, and Hygiene for Development*

Introduction

Globally, of the 2.1 billion people who do not have access to safe drinking water, 80% live in rural areas (World Bank, 2017c). Though the number of people living without clean water was halved between 1990 and 2010 (UNICEF, 2017), 25% of water points today are non-functional at any time (World Bank, 2017c). Additionally, 15% of water points completely fail within the first year, and 25% are non-functional within four years (Banks et al., 2016). These failure rates are due in part to a lack of planning, implementation, and post-construction support. Additionally, there are many factors that may influence the sustainability of a water system, including technical, human health, social, mechanical, environmental, and political factors (Barnes, 2009). There have been proposed universal frameworks for rural water supply, however; they do not address internal characteristics of a community that may influence water system sustainability (Hutchings et al., 2015).

In rural Haiti, many water systems quickly fall into disrepair due to a long history of political instability, natural disasters, and a lack of coordination in the water sector (Dowell et al., 2011; Rayner et al., 2016). Distrust of the government, particularly in rural areas, is common, and resistance to pay for water from many communities is a result of lack of transparency and a growing distrust of those who are responsible for operation and maintenance (O&M) (Rayner et al., 2016; World Bank, 2017a). To supply safe drinking water in rural communities and build capacity for ongoing delivery, it is essential to have a coordinated approach (Gelting et al., 2013; World Bank, 2017a). This involves understanding the context and perspectives of those for whom the water system was created for.

In the rural community of Timo (described in Chapter 1), there have been growing concerns regarding the sustainability of the system. There are a few main informants, however, little was known about the experience and perceptions of the community. This research aimed to understand the experience of those using the gravity-fed water system in rural Haiti to better inform HHI in their collaboration with the community. There are many proposed frameworks that are used to describe the sustainability of water systems; however, rather than placing the data into a pre-existing framework, I worked inductively, allowing for new ideas or concepts to emerge (Mayan, 2009).

Methods

Due to the desire to stay close to the data, qualitative description was the chosen method for this study. Qualitative description is less interpretive than other qualitative methods, allowing researchers to stay close to their data and provide a surface level description and comprehensive summary of the data (Sandelowski, 2000).

This study was guided by a community-based participatory research (CBPR) approach (Minkler, 2004). CBPR is not a method, but rather an orientation to research (Minkler, 2004). The foundations of CBPR emerged in the 1970's from the work of scholars who conducted research in oppressed/developing communities (Freire, 1970). These scholars desired an approach to research that focused on an equal partnership between researchers and community members. These partnerships would result in a project that was relevant and important to the community, focused on capacity development, and addressed the power dynamic that was commonly found in more traditional ways of research (Minkler, 2005). Today, CBPR has been defined by Minkler (2005, p. 3) as:

[A] collaborative process that equitably involves all partners in the research process and recognizes the unique strengths that each brings. CBPR begins with a research topic of importance to the community with the aim of combining knowledge and action for social change to improve community health and eliminate health disparities.

Three interrelated elements of CBPR are participation, research, and action. Ideally in CBPR, the community brings forth a topic of concern to the researcher. However, it is often the case that it is the researcher who reaches out to the community. Because of this, it is important that there is a continual commitment to the communities concerns and desired topic (Minkler, 2005).

Regarding this thesis research, participation was fostered through conversations with the organization and community leaders in order to identify a research question that was important and relevant. As well, throughout the entire research process, the community was actively involved. Community members not only contributed to the research question, but also supported the development and process of the qualitative interviews and subsequent transcription. Finally, the 'action' piece of CBPR guided Knowledge Translation (KT) through the creation of relevant and accessible recommendations, community reports, and presentations for the community and HHI.

Information Gathering and Community Engagement

Having travelled to Timo prior to the start of this project, I had a basic understanding of the water system in the community and a relationship with HHI and Timo community leaders. I approached HHI and inquired about their interest in a research project being conducted on the water system in Timo. Initial conversations with HHI surrounded their concerns regarding water quality and investigating the potential of installing centralized water treatment in the water system. Following this conversation, I travelled to Timo in 2017 to engage with residents about what their primary concerns about the water system were. Security, water point structure, and water pressure were often what residents spoke about. Although treatment was brought up by some residents, it was more about confusion surrounding responsibilities regarding supply and management of treatment. Following the trip in April 2017, I reconnected with HHI and proposed that rather than focusing on water quality, aspects related to water system management and water access appeared to be of higher concern for residents. This was confirmed through connecting with two community leaders in Timo. I created a PowerPoint presentation that was translated into Creole, describing what the proposed project would look like. I later spoke on the phone with them via translator and confirmed that a focus on management and user experience was of concern and should be the direction of the research project.

The research interview questions were created in collaboration primarily with three HHI members – one of who is Haitian – and a locally hired research assistant (RA) for the research project. I met with HHI members and RA via Skype to go through each question, ensuring that it was culturally relevant and would be understood by participants. Though some of the questions changed throughout the interview process while I was in Timo, the RA was heavily involved in the revisions of the interview guide. I had worked with my RA as my interpreter in 2017. They are well respected in the community, had previous experience in qualitative interviewing, and had been trained by both HHI and myself regarding the nature of this research project.

Theoretical Perspective

A researcher's theoretical perspective refers to the way in which the researcher views their place in the research, how information is gathered, and how it is understood (Mayan, 2009). I approached this research with a relativist ontology and subjectivist epistemology. A relativist ontology acknowledges that there are multiple realities and truths that are influenced by people's individual or collective experiences. Subjectivist epistemology employs the perspective that the researcher and participants work together to co-create knowledge and understanding (Denzin & Lincoln, 2005). A subjectivist epistemology also acknowledges the relationship and implicit biases that the researcher has that influence the research. My theoretical perspective aligns closest with critical theory, which focuses on countering the unequal distribution of power that is often in dominant research (Kincheloe & McLaren, 2005).

Sampling

Purposeful sampling (Mayan, 2009) was used in order to find information rich cases from knowledgeable informants with a wide range of experiences using the water system in Timo. This included sampling from each of the five reservoir systems in addition to those who identified as being responsible for the water system. Inclusion criteria were resident of Timo, experience with the tap water system, and over the age of 18. There were no exclusion criteria.

Guided by a CBPR approach, since the RA was familiar with the location of community members and had an understanding of who would be more willing to be interviewed, they created a list of 10 people per reservoir that could be reached out for an interview prior to my arrival in the community. Occasionally, participants would be unable to be interviewed due to harvesting season and frequent market days. In addition, there were some participants who refused to be interviewed. According to the RA, this was because they had not had water in their taps for over a year and were upset with the situation. In some cases, these were people who had participated and contributed the most in the expansion of the water system.

Data Generation

From May 22 to June 25, 2018, 22 residents were interviewed using a semi-structured interview guide. Since little was known about the experience of the residents in Timo, interviews were intended to be unstructured (McIntosh & Morse, 2015). It was recommended that I not be present in the interviews as both the community leaders and HHI believed that my presence in the interview would bias responses. Therefore, interviews were conducted by the RA. The interview guide took somewhat of a semi-structured nature in order to guide the RA through the questions and to ensure that details were described in areas that may have been a shared or taken for granted understanding between the RA and participant (Williamson et al., 2011). There were no additional research assistants/interviewers in the project in order to maintain consistency.

Interviews were completed in Haitian Creole. Approximately two interviews were completed each day. At the end of each day, I would transcribe the recording into English as the RA listened to the audio recording aloud and translated. The RA met the participants at their house or community centre depending on the convenience for the participant. Due to the low literacy rate of many of the residents, the information and consent form was read aloud to them. Verbal consent was confirmed with a signature from the RA. I desired to provide an incentive for participants that may be useful to them in addition to not requiring any additional maintenance costs. After consulting with HHI and the RA, a wind-up flashlight was given for each interview. Field notes were taken by the RA during the interviews and I also took field notes while in the community.

Member checking (Birt, 2016) was conducted after all the interviews had been conducted. I went through each transcript and created a summary of what I understood were the main points from the interviews. Of the 22 participants, eight attended the meeting on June 14, 2018. The member check was conducted in the community centre. To create a more collaborative space, benches were set up in a circle. As the RA translated, I went through the summary, ensuring that I had understood what participants had said in the interviews in addition to asking any clarifying information. I took notes during this time and the member check was also recorded and transcribed into English for analysis.

Data Analysis

Content analysis was used as the analysis technique, utilizing NVivo 12 Plus (QSR International, 2019) to organize the data. Initial coding of the data occurred daily in Haiti during the translation and transcription of each interview. In doing so, adaptations to the interview guide could be made to follow-up on points of interest. Once I had arrived back in Canada, I read through each transcript again, making note of any interesting words or phrases and identifying patterns that occurred in the interviews. Following the coding, phrases or concepts that were similar or had a common underlying pattern were placed into categories. I then ensured that each code fit within the category it was placed in, and that the categories themselves were distinct from each other - known as internal and external heterogeneity (Mayan, 2009).

Although the RA could not be present for the bulk of analysis that occurred in Canada, I reached out to my RA if I required any clarification in the transcripts. Once I felt that I had a clear understanding of the data and categories, I shared my findings with my RA to ensure that it reflected what their perceptions of the interviews were and receive their feedback and clarification.

Rigor

Rigor in qualitative research was first addressed by Guba and Lincoln (1981) as they argued for an alternative way to speak about rigor without following the quantitative criteria of validity, generalizability, and reliability. Guba and Lincoln’s development of alternative evaluations for qualitative research sparked a proliferation of scholars proposing various new criteria for rigor over the past 30 years (Mayan, 2009).

The most important pieces to consider when choosing criteria for evaluating rigor in qualitative research is based on the nature of the research and discipline it is situated in. This project followed the criteria proposed by Tracy (2010) regarding quality in qualitative research in addition to the criteria derived from Lincoln and Guba (1985). The criteria used were: credibility, applicability (worthy topic, significant contribution), dependability (rich rigor, meaningful coherence), confirmability (sincerity), and ethics. The terms as described by Tracy are in brackets.

Credibility

Credibility is described as the ability to provide a rich, accurate, and representational description of the data and participants (Mayan, 2009; Tracy, 2010). To ensure credibility, I spent a prolonged time in the field to gain a better understanding of the community and culture. I debriefed with my research assistant after every interview as we went through the audio recordings together. I took note of when my research assistant pointed out a specific word or when they described the demeanor of the participant during the interview or at a specific point in the interview. Williamson et al. (2011) stresses taken-for granted assumptions or shared understandings that the interviewer and research participant would have that may not be known to the researcher, resulting in the interviews being shorter or less detailed. At points where it may have been beneficial for there to be more information asked from the participant about a topic, I referenced this point in the transcription and gave the research assistant an example of how they might gain further understanding in following interviews. Credibility was also ensured through member checks that were completed with participants to ensure that I understood what they had said in the interviews (Mayan, 2009).

It is important to acknowledge that the use of a translator/interpreter in cross-cultural interviews may pose challenges in ensuring validity and credibility (Kapborga & Bertero, 2002; Williamson et al., 2011). The research assistant had their own perspectives and biases that may have influenced the way that they interviewed, explained certain contexts or summarized what the participant had said. In order to address these challenges as much as possible, the research assistant was trained in qualitative methods, understood the research goals, the reasoning behind each question, and was instructed to translate verbatim (Williamson et al., 2011).

Although the research assistant was from the community and had a relationship with many participants, it was strongly believed by the partnering organization that my status as an outsider (Mayan, 2009) and being seen as connected to HHI would have influenced participant responses. Therefore, I honoured the wishes of the community and agreed with the decision of not being present for the interviews. This also aligns with the CBPR approach taken for the research.

Applicability

Though Lincoln and Guba's (Lincoln et al., 1985) initial definition of applicability is it's transferability or external validity, this project focused more heavily on the contribution it could make to a specific community. This was met through ensuring worthy topic and a significant contribution (Tracy, 2010). Ensuring a worthy topic includes choosing a topic that is relevant, timely, and significant to the community (Tracy, 2010). Following a CBPR approach, the research question was created in partnership with the organization. To confirm significant contribution as described by Tracy (2010), knowledge translation was to be practical, moral, and methodological. Involvement of the organization and community ensured that the recommendations for the community and organization based on the research findings were applicable and feasible.

Dependability

Lincoln et al. (1985) describe dependability as the ability to understand how decisions in the research were made, typically though the use of an audit trail. The two criteria posed by Tracy (2010) linked to this concept are rich rigor and meaningful coherence. Rich rigor encompasses strategic and consistent data collection and analysis processes (Tracy, 2010). This was achieved by completing the armchair walkthrough (Mayan, 2009), which ensures that the data collection and analysis processes are consistent with what the method requires. Meaningful coherence was met by following through on what the initially stated goals of the project were and effectively connecting the project findings to the literature (Tracy, 2010). This was achieved through continually reflecting on what I had originally stated and planned at the beginning of my project with the stakeholders. An audit trail was also created to account for any changes that were made and the reasoning behind it (Morse et al., 2002).

Confirmability

Confirmability in qualitative research as described by Lincoln et al. (1985) is to ensure that the findings are logical by examining the data and it's interpretations. Tracy (2010) describes this as sincerity. Strategies for ensuring sincerity are through reflexivity and being transparent (Tracy, 2010). To reflect on my experience and how my perceptions and biases influenced the research, I kept a detailed personal journal throughout the project.

Ethics

According to Tracy (2010), procedural, cultural, relational, and exiting ethics must all be considered in qualitative research. Procedural ethics is ensuring that participants are protected against any unnecessary risk due to their involvement in the study, including confidentiality, anonymity, and privacy (Tracy, 2010). Three core principles of procedural ethics that must be considered throughout the project are respect for persons, concern for welfare, and justice (Mayan, 2009). Prior to formal data generation, ethical approval was gained through the University of Alberta, Haiti Health Initiative, and the Department of Health in Haiti. Confidentiality and anonymity were ensured by removing names from transcripts and establishing the consent form signed by the RA that outlined what information will remain confidential within the study.

Cultural or situational ethics encompasses ethical behaviour throughout the various situations that may be encountered in the study, particularly while living in the community of Timo. It was important that during my stay I respected the cultural norms of the community, including being cognizant of how I dressed, how I spoke to people, my body language, and respecting the religious/spiritual practices in the community. My RA was very useful to me in this regard, as he assisted me in appropriately presenting myself.

Relational ethics includes the dynamic of the interactions between the researcher and participants, and how the actions and character of the researcher and their study impacts the participants (Tracy, 2010). Being an outsider to the community in various ways, building trust and rapport in the community was imperative. I believe that I achieved this through spending time with families and their children, speaking the local language (Haitian Creole) whenever possible, and participating in community activities. To address the power dynamic as a researcher in the community, having the interviews being conducted by a local community member alleviated some of this concern.

Exiting ethics encompasses how the researcher leaves the site or community and subsequently shares their results within academia. Ensuring that my results appropriately reflected my research and fit within my scope and literature review is also crucial, in addition to appropriately presenting my findings and participants in a respectful and accurate manner. Although I do not have control over how my findings are read, I must ensure that my research does not have any unintended consequences for the residents of Timo or HHI.

Findings

There were three main findings that emerged from the data: Perceived increased quality of life due to the water system, initiative to maintain the water system, and lack of community cohesion. Figure 7 is a visual representation of the findings and how they may interact with one another, ultimately influencing the sustainability of the water system. Improved quality of life and community cohesion are not perceived as interrelated; however, importance of the water system and community cohesion both seemed to influence the degree to which there is initiative to maintain the water system. It is important to clarify that initiative to maintain the water system represents the relationship the community has with the water system, whereas community cohesion is the relationship the community members have with one another.

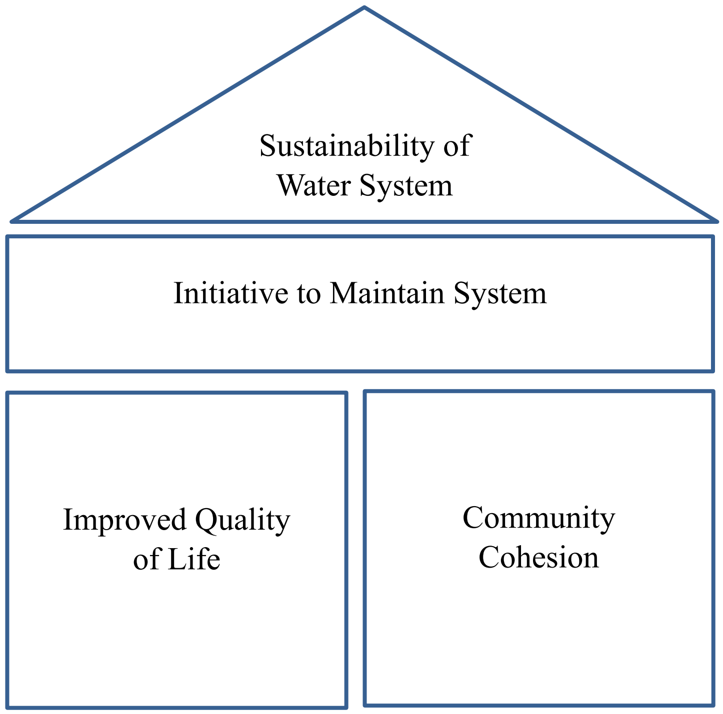

Figure 7. Visual representation of findings

Improved Quality of Life

Residents of Timo indicated three ways they perceived the water system had on their lives: decreased concerns about water contamination, decreased hazards when retrieving water, and increased convenience.

Many residents felt that the water system addressed contamination concerns that existed when the community was reliant on surface water. Participants reported that before the water system was installed, garbage would be frequently found in the stream or hand dug holes. Livestock such as cows and horses would be brought to use these surface water sources, contaminating the water source with feces:

Before we had the water system, we struggled a lot because when we retrieve water from the source, we used to see animals come to drink in the source. It is like there is no difference between us and the animals, they are drinking the same source. We know that we are drinking water in a bad condition (Participant 14, Nan Micho).

Additionally, two participants described contamination of the source due to mystic devotions – praising a spirit by combining various items (food, pop, sparkles) into a hand dug water source. One participant explained that people would leave their dirty laundry near the source. Sickness caused by contaminated water was also a concern for residents before the water system was installed.

Residents of Timo also felt that once installed, the water system alleviated safety concerns related to previous water retrieval, "but now if we need water, we are not going to risk our life to find it" (Participant 19, Nan Micho). When it would rain, some participants would "use[d] rainwater because the route was in a bad condition, it was very slippery" (Participant 10, Kay Maten). One participant spoke about animals getting injured while retrieving water on the precarious path. Rocks would fall and hit people's heads while they were walking to retrieve water, in one case causing a community member to be paralyzed. Participants felt that they no longer had to worry about their family members being injured because the route was safer:

The water system represents a saviour for us. I say that because in the past, when you send a kid to retrieve water, you didn't feel at peace because most of the time rocks are falling down in the route from the mountain and if you don't see the kid return back very quick and you have to go and see what happened (Participant 10, Kay Maten).

Finally, participants felt that the installment of the water system decreased the distance they had to walk to retrieve water. For many residents, this meant that they had time for other activities. For two participants, having water in their yard meant that their children would not be late for school. One participant reported that for older people, “they cannot go so far to take water, and when HHI came to work in the water system to improve it, we find the water easier” (Participant 5, Gran Platon). Another participant described how when she would use the river for laundry and cooking, “it takes me so long. When I am back home, it is dark, and I don’t have time to do other things” (Participant 20, Nan Tet Dlo).

Lack of Community Cohesion

As mentioned in the introduction of the findings, community cohesion represents the relationship that community members have with each other as a whole. A lack of both collaboration and communication influence the perceived lack of community cohesion as described by participants. Though there are some members who are willing to work together to maintain the water system (discussed in the next finding), many participants described a feeling that the community did not work well together.

Many participants expressed feelings of general lack of collaboration in the community, sensing that others in the community would not be willing to contribute to maintenance or repairs of the water system. Participants spoke about not receiving assistance from other residents in the community when they clean the system, even if they have taps in their yard: “They just don’t want to help. It’s not because they don’t find water in the tap. They just don’t want to collaborate” (Participant 6, Tifon). Another resident described how her husband is left with the responsibility to repair the water system because other people will not contribute, discouraged by the lack of collaboration in the community in general: “In this community, if there is something you can do by yourself, do it, but if something that needs collaboration, you don't want to try. If it is something that requires help from the community, don't even try" (Participant 21, Nan Tet Dlo).

Two participants described how people speak poorly about them when they work on the water system. Another participant explained that others in the community are not willing to collaborate because they are not part of the water committee: "We had a water committee, that is why we are responsible. Even if you ask for help from others, they will say that they are not in the water committee, that is your responsibility" (Participant 10, Kay Maten).

Regarding monetary contribution, although many participants personally said that they would contribute, many reported that their fellow community members would be unwilling to contribute or collaborate. They described how some community members may try to avoid paying for water by saying that they could access the river for free or that they do not have money to give. Other participants reported that a reluctance to contribute money was because many people thought that the water committee would keep the money for themselves or that they are already getting paid by HHI:

> Some people will say that you will keep the money for your own. They will not give you. It is not something easy to find, people to give you money to buy supplies to repair the pipe. They will say to you that they didn't break the pipe. They do not have to give money to do repairs (Participant 9, Kay Maten).

Community cohesion has also been impacted by the presence of another organization and conflict related to who is to be responsible for the cleaning of one of the reservoirs located on the premises of the new organization. The new organization has taken responsibility over one of the reservoirs and changed the key. The previous people responsible for cleaning the reservoir have attempted to ask for the key in order to clean it but have been met with resistance:

That is why when we decided to clean it, we cannot. I asked ___ and ___ (committee members) for the key, they say they don't know where it is. Until now, we can say nothing, we just leave the water system without cleaning (Participant 14, Nan Micho).

A lack of planning communication within those who clean the water system is affecting how the community members perceive those responsible. There are no longer meetings being held by those who clean the water system, which has affected how the community is communicated with, "____ (WC) used to clean it every month. He used to put some chlorine in it. I don't know what happened to him, he doesn't do that anymore (Participant 21, Nan Tet Dlo). Two participants expressed that they do not receive any notice or explanation when their tap is turned off, and an additional participant explaining that they felt disrespected because of this, furthering lack of community cohesion. When asked about why they thought the water committee does not communicate with them regarding water turn off, a participant felt it was "because they have no respect for the population" (Participant 18, Nan Micho).

Initiative to Maintain the Water System

Though residents said that they did not feel like their fellow community members supported them, there is also a desire to maintain the water system. There is a small group of people who contribute together to maintain the water system. These participants stated that they did not want to have to wait for HHI to repair the system for them and that the population should be taking better care of the water system, acknowledging that assistance is not always there to help them when problems arise:

The reservoir needs a lot of repairs. I don't think the population needs to wait for the foreigners to do that. I don't think that it's a good idea to wait for the foreigners to help us all the time (Participant 7, Tifon).

There are residents in the community who have taken initiative to repair the water system with what they have, even though they do not have any formal training or equipment to repair the pipes. Furthermore, although there is not an official or established way of raising money for supplies, there are residents who either combine money together or purchase resources individually, including chlorine, glue, gas, or covers for the catchment/reservoir, "Sometimes I don't have equipment supplies to repair the pipe, but I do my best to fix it" (Participant 19, Nan Micho). One participant expressed their dedication to the water system regardless of receiving finances, "When the problem happens, I went to my toolbox to see if I have supplies to fix it. If yes, I just fix it. But I don't get paid for that" (Participant 19, Nan Micho). There were also participants that reported caring for the water system even though they are not members of the water committee:

I do everything for the water system. I clean it, repairing, it's me. If something bad happens to the water, it's me that my neighbours call. I am not a committee member, I am still not a committee member but if something happens, they call me (Participant 7, Tifon).

Though there is a desire to have more independence in maintenance and repairs, participants still desired a level of support from the organization in a variety of ways. This included financial support to help with larger fixes and supplying locally unavailable materials and equipment:

I don't think we can wait for HHI to repair pipes. But if the water system is destroyed, HHI could help with construction. If we don't have resources available when the pipe is broken to call someone to repair it, even if that person says they are going to come and fix it, it is going to take time (Participant 14, Nan Micho).

Another participant suggested having the water committee be trained by HHI about leadership and communication with the community so that they can work together to solve problems:

A proposition that I have is I would like a training for the water committee to let them know when there is a problem, don't try to keep the problem for themselves, but they have to let the population be involved in this problem (Participant 12, Kay Maten).

It was also suggested that the committee send reports to HHI, alluding to the importance of accountability: "Yes, it's good. It's good to have a committee to supervise the lines and give a report to HHI" (Participant 10, Kay Maten). Three participants suggested a community meeting to discuss what can be done to improve the system together. Finances were also discussed to, suggesting putting money together to purchases materials for cleaning:

If we value the water, we will do a meeting, we will put together to see what is going good and what is going bad. Once we identify the problem, if there is a glue, we can just put money together to buy the glue and we can clean the water to avoid microbes (Participant 21, Nan Tet Dlo).

Discussion and Conclusion

These findings provide original insight into the experience of rural Haitians using a gravity-fed water system. The three main findings that arose from this study were that participants perceived the water system improved their quality of life, there was an initiative to maintain the water system, and that there was a lack of community cohesion.

Though many studies regarding sustainability of water systems have been completed in African countries (Fisher et al., 2015; Foster, 2013; Hall et al., 2015; Klug et al., 2017; Mann, 2003; Rondi et al., 2015) and few completed in Haiti, there are many similarities and comparability that can be made. (Rayner et al., 2016; Russel et al., 2015; Varma et al., 2008; Widmer et al., 2014; Wilner et al., 2017).

In a survey of United States Peace Corps Volunteers who had worked in developing countries implementing water supply systems, Hokanson et al. (2007) emphasized the importance of the community understanding the impact of the water supply and improvement of health in the community. It is evident that Timo residents appreciate and understand the importance of the water supply system. Rayner et al. (2016) described an appreciation for the economic and health benefits from an automatic chlorinator installed in a gravity-fed water system in southern Haiti. Though this is not related to the overall use of the water system and rather the specific addition of the water system providing cleaner water, this is still relevant as it represents perceived improvement from what they had before, which is similar to what the Timo residents experienced in regards to initially relying on surface water. Montgomery et al. (2009) defines effective community demand as one of the universal sustainability factors in rural Sub-Saharan African water supplies. Effective community demand is linked to the community seeing the importance of and adopting the water system (Harvey et al., 2006). This was evident through residents explaining the positive impact the water system had on their lives. With effective community demand, individuals are more likely to be willing and able to maintain the system and be willing to pay for operation and maintenance costs (Montgomery et al., 2009).

In Timo, perceived lack of community cohesion was described to impact maintenance and access in the water system. A concept closely linked to community cohesion is social capital. Social capital is "social structures that foster cooperation for the good of a community" (Kelly et al., 2017). A lack of social capital is a barrier to collective action in community water systems and is imperative to sustainability in regions where there are weak legal structures (Bisung et al., 2014). Social capital can be separated into structural social capital (organizations and networks that facilitate group cooperation) and cognitive social capital (the trust and reputation that an individual person possesses) (Kelly et al., 2017). Structural social capital may be influencing community cohesion in Timo regarding the two community organizations being present in the community that do not have shared values and visions of their work in Timo. Some residents have taken sides between these two organizations, which may be affecting how the two water committees interact with one another. In addition, it appears that there may be low cognitive social capital in the community, as many residents described the general lack of collaboration in the community. Finally, Barnes and Ashbolt (2014) found that in water supply systems in the rural Philippines, a main factor that community members attributed to successful and sustainable projects was "unity and good relationships within the community", which included between community members themselves, and between development workers (organizations) and community members.

Kelly et al. (2017) questioned exactly what the relationship is between social capital, community participation, and sustainability. This research supports the findings of Bisung et al. (2014) that social capital impacts community participation in maintaining the water system through the influence that social capital (both structural and cognitive) has on community cohesion.

Participants described that many Timo residents do not want to pay a fee for their water services partly due to distrust that their payments would not be appropriately used. This has also been found in other studies completed in Haiti in regards to this topic (Rayner et al., 2016; World Bank, 2017a). In their systematic review of success factors in Sub-Saharan rural water supplies over the past 30 years, Hutchings et al. (2015) state that institutional transparency is an imperative component of water supply sustainability. Additionally, Montgomery et al. (2009) list local financing and recovery as one of three universal factors of sustainable water supplies, with mistrust of local water funds as a main obstacle to achieving this.

This research speculates that enhancing communication between community members is a potential solution to a lack of community cohesion or low social capital. Although it is unrealistic to expect all members of a community to have similar interests and a desire to work together, a clear understanding of the expected roles of community members may improve sustainability and willingness to pay. However, having trust in communication is critical. Even if the community is being openly communicated to, if they do not trust the source of the communication, it is unlikely to be impactful.

The fact that the community was part of creating the water system from its beginnings with the local organization in 1994 has likely influenced their initiative to maintain the system. Technology choice is a critical aspect in communities taking initiative to maintain their water systems (Barnes & Ashbolt, 2014; Breslin, 2003; Gleitsmann, Kroma, & Steenhuis, 2007; Hunter, MacDonald, & Carter, 2010; Montgomery et al., 2009).

Residents described having initiative to maintain the water system, and that they had a desire to take on this responsibility even in the absence of Haiti Health Initiative. As cited in Hutchings et al. (2015), this is described as collective initiative and is an imperative component in the sustainability of rural water supplies. Alexander et al. (2015) assessed the governance and functionality of community water schemes in Ethiopia, focusing on water committee members. Water committees having the capacity to perform minor repairs were associated with higher functionality.

Though there was initiative to have more responsibility for the water system, many participants described that they still desired support from the organization. In a systematic review of 174 successful community managed water supplies (Hutchings et al., 2015), long-term external support was a required ‘plus’ factor. Reflecting on the idea that community-participation (giving the power to choose technology, tariffs, and level of responsibility) is key to the sustainability of a rural water supply (Harvey et al., 2006), understanding what aspects of support are requested from the community and what level of responsibility they desire is critical in increasing capacity and sustainability of rural water supplies (Breslin, 2003; Gleitsmann et al., 2007; Harvey et al., 2006). Barnes and Ashbolt (2014) also found that commitment and willingness for community members to take initiative in water supply maintenance was a reason for project success. It is unrealistic to expect communities to sustain a water supply on their own without any external support whatsoever. In many regions, there may be a lack of governmental support to help communities with operation and maintenance. In the case of many rural communities in Haiti, residents do not support the presence of the federal government in the water system. Therefore, organizational external support is critical in the sustainability of water supplies and building capacity for communities to take more ownership over time (Hunter et al., 2010).

Strengths

This is the first qualitative study to explore the experience of rural Haitians regarding water systems. Having travelled to the community twice before, I had built rapport and was able to understand the context of the community because of this. Having a local resident of Timo complete the interviews increased capacity within the community due to them gaining further education and income.

Limitations

Due to the nature of translation, the meaning behind some words in Creole were lost when translated into English. The research assistant did their best to explain the meaning behind the words that did not directly translate in order to conserve as much context as possible. Unfortunately, back-translation was not feasible due to cost and time constraints. Due to this, credibility of the translation may be questioned. Interviews were done quite rapidly in a short period of time, leaving little time for reflection and follow-up interviews. Harvest and market season in addition to a new school construction resulted in many participants being very busy and away from their homes during the interview process. Finally, the research was focused on a specific rural community in Haiti and the findings may not be representative of other regions in Haiti or abroad.

Knowledge Translation

Knowledge translation (KT) is a critical piece of the research process as it transforms the research findings into an understood and tangible message for the populations that is most relevant to, also known as knowledge users (Canadian Institutes of Health Research, 2015). In this project, the KT plan followed a CBPR approach and thus was centred around the co-learnings of all stakeholders.

The primary KT plan for this project was an Executive Summary that was created for the community, HHI, and Haitian government. I met with HHI members to go through the Summary and recommendations based on the findings. The Summary will be translated into Haitian Creole and presented to the community. The presentation will also include receiving their feedback and input on next steps. Due to the current political instability in Haiti, HHI trips to Timo have been suspended. However, I am maintaining my relationship with HHI through my new role as WASH Lead on the Board of Directors and intend on seeing through the recommendations proposed in the Summary. Ideally, I will travel back to Timo in April 2020 to present the findings of the project and start on the recommendations. I have also been invited to present my findings and recommendations to the Ministry of Health in Haiti. This is an important piece in enhancing the communication between rural communities and the government in Haiti and creating a more cohesive water system structure in the country.

Recommendations for HHI

Many participants described a desire to have HHI support them in water system maintenance. I recommended that HHI meet with community members to determine the level of external support desired. This would include how much financial involvement HHI would have, what materials or resources need to be supplied from outside of Haiti (and the frequency of need), and any training that is required. Training would include the names of water system parts and a means of reporting for the committee in order to enhance communication between the committee, community, and HHI.

Secondly, there was a perceived lack of trust between the community members and water committee regarding where finances were spent. I recommended that HHI meet with the community and clearly communicate its role within the water system, particularly where finances are allocated. This may increase trust within the community to contribute money when the committee asks for contributions in the future. Furthermore, creating a legitimate bank account in the nearest town (Tom Gateau) may enable a more official means of managing money and increase transparency.

Finally, I recommended HHI complete a Water Safety Plan (WSP) (World Health Organization, 2012) with the community. A WSP can be utilized in both new and existing water schemes and in a variety of settings, levels, and scales to aid the management of the system. They are flexible and adaptive, intended to strengthen the capacity for small, remote communities to have cost-effective management for their water supplies to remain reliable and safe. They are meant to be used by communities (including any entity working with them) to proactively manage the water supply system.

Directions for Future Research

Specifically related to Timo, further work should focus on determining exactly what is desired as external support for the community. In addition, exploring ways to increase trust regarding the use of financial resources. This could be through exploring the different kinds of finance systems the community is most comfortable with or is the most transparent. Though some participants of the study identified as water committee members, it may be useful to specifically understand their collective experience in using and maintaining the water system.

This research provides original insight to the experience of a rural Haitian village and water supply sustainability. The findings suggest a relationship between perceived importance and community cohesion on initiative to maintain the water system. Improving the understanding of the factors influencing the sustainability of rural communities and communicating with external support and governing bodies is crucial in creating long-lasting and rippling effects in community health and economies.

Chapter 4: Evaluating the Microbial Water Quality of a Gravity-Fed Water System in Rural Haiti

Introduction

Understanding the microbial water quality and its potential effect on human health can aid in a more coordinated approach to sustainable water supply systems (Barnes, Ashbolt, et al., 2014). Previous water testing had been completed in Timo (described in Chapter 1), but the results were inconclusive due to the time between sampling and testing being outside quality assurance limits (American Public Health Association, 2017). The use of a more suitable field-testing method was desired to gain a more accurate understanding of the microbial water quality.

Timo Water Supply System

There are currently five raw water reservoirs leading to 53 standpipes/taps (Table 3), serving over 1,000 people in the Timo community. All distributing pipes run above ground in 60 mm high density polypropylene (HDPE) pipe. Figure 7 provides an example of a reservoir, standpipe tap, and distribution pipe in Timo.

Table 3. Timo reservoir line information.

Reservoir	Reservoir Volume (L)	No. of Branches	No. of Taps
Kamaten	3,995	4	17
Gran Platon	16, 963	3	18
Tifon	8,641	3	6
Micho	12,032	3	9
Tet Dlo	3,947	1	4

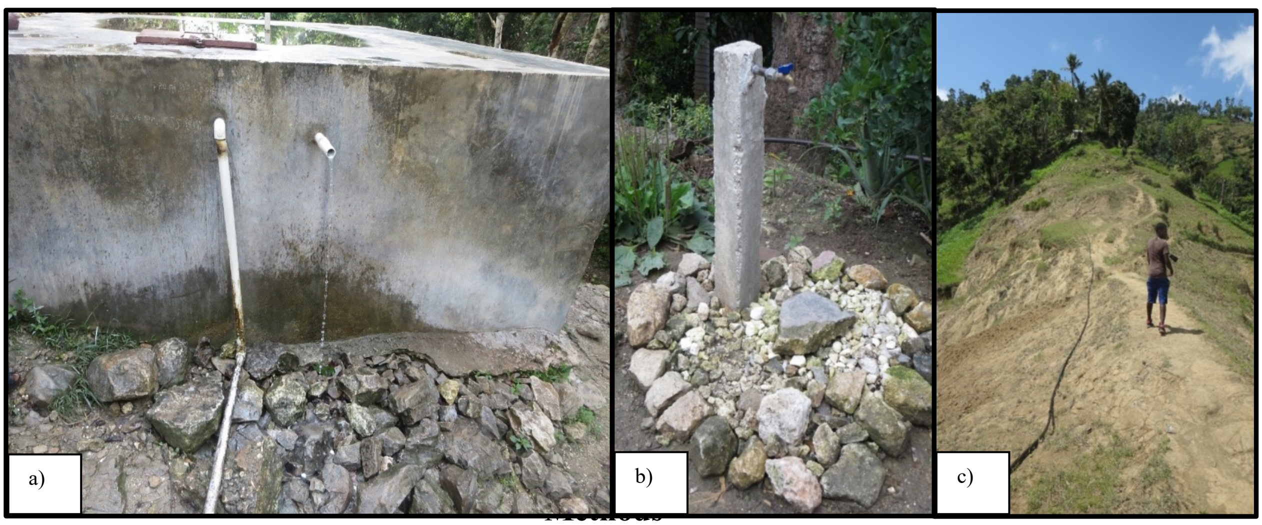

Figure 8. Timo water system elements.

a) Raw water reservoir, b) standpipe tap, c) HDPE distribution pipeline.

In May – June 2018, water quality testing of 15 of the taps was completed using Aquagenx CBT *E. coli* Kit® (described in Chapter 1). This test was chosen because an incubator was not required, and results could easily be read within 48 hours in the field. Due to financial constraints, all 53 taps, reservoirs, and catchments were unable to be tested. Therefore, in order to gain an understanding of microbial water quality and identify potential points of faecal contamination, each reservoir, a tap half-way down the line, and a tap at the end of the branch was tested. This was met with some barriers, as there were multiple branches to many of the reservoir lines and many taps were not functional. This resulted in testing being completed at the nearest functional tap. Testing was completed in 5 days; each reservoir was taken on a different day in the week at relatively the same time.

I was accompanied by the local HHI RA and water master. A 100 mL water sample was taken using a sterile container provided by Aquagenx. Aquagenx EC+TC® growth medium was added to the sample and was shaken until completely dissolved. The sample was then poured into an Aquagenx Compartment Bag®. The bag was labelled for time and location. A Whirl-Pak seal was fastened to the top of the bag to prevent water leaking or movement across compartments. The samples were placed in a locked room at ambient temperatures (ranged 25 to35 °C) for 48 hours for incubation. To dispose of the samples following scoring and recording of the test results, three chlorine tablets were added to each Aquagenx Compartment Bag®. After 45 minutes, the contents were poured into a hole in the ground and the compartment bag was safely disposed of.

Results

The results from the 15 water samples collected (three from each reservoir line) are summarized in Table 4. Tap locations in each reservoir line are listed from the top location to the furthest from the reservoir. In the column named 'Blue Compartments', the number indicates the compartment number that indicated a positive result (out of five). Confidence Interval (C.I.) is also included. An example of positive (blue) coloration in the Aquagenx CBT® for *E. coli* is provided in Figure 8. Table 5 depicts the number and percentage of samples in each World Health Organization Health Risk Category; noting that 40% of samples were identified as 'Probably Unsafe' or 'Unsafe for Consumption'.

Table 4. E. coli results from the Timo water supply system**.**

Reservoir	**Location**	**Blue Compartments**	**MPN /100 mL**	**95% C.I. /100 mL**	**Health Risk Category**
Kay Maten	Reservoir	2	1.2	5.64	Intermediate
	Edmund	2	1.2	5.64	Intermediate
	Destin	0	0	2.87	Low
Gran Platon	Reservoir	1,2,3	13.6	83.06	High
	Bibi	1,2,3,4	48.3	351.91	High
	Nan Woch	1,2,3,4,5	>100	9435.1	Unsafe
Tifon	Reservoir	1,2,3,4,5	>100	9435.1	Unsafe
	Rico	1,2,3,4	48.3	351.91	High
	Liwa	1,2,3,4	48.3	351.91	High
Nan Micho	Reservoir	0	0	2.87	Low
	Valme	0	0	2.87	Low
	Remi	0	0	2.87	Low
Nan Tet Dlo	Reservoir	1,3	3.4	12.53	Intermediate
	Community Centre	1,2,3	13.6	83.06	High
	Community Centre Tank	1,2,3,4,5	>100	9435.1	Unsafe

Table 5.Total samples in each WHO Health Risk Category.

Health Risk Category	**Samples**	**Percentage of Taps**
Low Risk/Safe	4	26.7
Probably Safe/Intermediate Risk	2	13.3
Possibly Safe/Intermediate Risk	2	13.3
Possibly Unsafe/High Risk	1	6.7
Probably Unsafe/High Risk	3	20.0
Unsafe	3	20.0

Figure 9. Example of Aquagenx CBT and results from Gran Platon line

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Regarding the likely place of faecal contamination in the Kay Maten line, there may have been surface contamination or at the tap at both the reservoir and Edmund tap (reservoir was taken from water pouring out of reservoir via pipe). At Gran Platon, the test samples became increasingly more contaminated with *E. coli* through the system. This may indicate possible points of cross-contamination within the community. The catchment cover at Tifon was in severe disrepair, containing a large hole in the rusted metal, which may have caused contamination and the increased levels of *E. coli* detected. Nan Micho line was the least contaminated based on the coliform results. At the time of the water testing, many residents were not using the tap connected to Nan Micho due to a contamination concern because of a very strong odor that many described as rotten eggs (i.e. hydrogen sulphide gas). This odor may result from decomposition of organic matter and reducing (anaerobic) environment due to the presence of iron. Nonetheless, *E. coli* detects implies faecal contamination with the organic matter. At the Nan Tet Dlo reservoir, there was a piece of wood and leaves that acted as a cover, likely contributing to the organic matter contamination of the reservoir and Community Centre Tap. At the Community Centre Tank, residents retrieve water by placing a buckets and containers inside the tank, likely contaminating the entirety of the tank with faecal matter from hands and contaminated containers.

Discussion

The findings of this project provide insight into the water quality and functionality of a gravity-based water system in rural Haiti. A foundational step in understanding water systems is to assess the microbial quality of the source (World Health Organization, 2012) which for the Timo system was often faecally contaminated (>50% of taps, Table 5). Not only was raw water in reservoirs contaminated, but also apparently further contaminated by the time water reached standpipe taps (Table 4).

The ethics of testing water quality testing in low resource settings must be acknowledged. Some testing is not necessarily better than none. If a test is to be used in a community, it must be of high quality to provide accurate and reliable results. Furthermore, the question must be asked of what change or good will come of knowing the quality of the water. If the water quality results indicate that the water is very poor, but the community has no other choice to drink it, what positive impact will that have, if any? Intention is imperative, but we also must reflect if our intention matches our impact in vulnerable communities. Hence, when addressing Timo's water system's sustainability, its management must be undertaken in collaboration with the community. HHI is committed to working with the community to address contamination hazards and risks, creating a higher capacity for concerns to be addressed.

There are no published results of Aquagenx tests completed in Haiti (Aquagenx, 2019a), so comparison in that regard is unavailable. However, there are comparisons that can be made with microbial testing studies conducted in other parts of Haiti. In an assessment of 345 non-surface water points in the Léogâne region, approximately 20% of improved (well) sources were contaminated (over 20 *E. coli* CFU/100 mL), (Widmer et al., 2014). Though the improved water sources did decrease faecal contamination, there was still a reported need for continual monitoring and evaluation in order to address the 20% of improved sources that were contaminated. Similarly, in Timo, although the water system is a protected source, there was a high degree of contamination. Widmer et al. (2014) stresses the need for continual microbial testing in these regions, particularly in Haiti, where the threat of cholera still looms.

Though many residents in Timo do not use unprotected (surface) water for drinking any longer due to the water system, the spring water may also be contaminated at the source. Water from at least 70% of evaluated springs near Verrettes were unsafe to drink based on the World Health Organization (WHO) drinking water standard (Wampler & Sisson, 2010). Further, Widmer et al. (2014) found that 50% of unimproved and 40% of natural springs were faecally contaminated in the Léogâne region (over 20 *E. coli* CFU/100 mL). In Gran Platon and Tifon reservoirs specifically, there is a potential that contamination is linked to the natural source. Further testing would be required to evaluate this, however.

Widmer et al. (2014) remarked that Community Health Workers had been told that surface water was being used for drinking due to concerns about well water. This is similar to anecdotal reports that many residents closest to Micho reservoir are not using the reservoir water to drink because of concern with taste, even though Micho was the least faecally contaminated according to the testing. In these cases, it is imperative to have clear and transparent communication with the community about their concerns with the water supply infrastructure.

Due to the simple testing and understanding of test results, the local research assistant was involved with and assisted in conducting water quality testing using the Aquagenx® Compartment Bag Test for *E. coli.* This was an important aspect of increasing the capacity within the community to understand how water quality testing is undertaken and interpreted.

Limitations of this project were that microbial testing was not completed in duplicates or triplicates, thus decreasing robustness of water quality assessment; however, given the number of tests along each segment, there was enough pseudo replication to be confident of the *E. coli* detected coming from the water system. The lack of replicates was due primarily to financial constraints. In addition, the inability to test the water at the true middle and end due to non-functional taps and multiple branches created challenges in fully understanding how microbial contamination may change throughout the system. Regarding the operations of the test itself, a limitation was that the testing kit did not come with as many seal clips as testing bags. This posed as a challenge when travelling through the valley and having to be very careful to not let compartments cross-contaminate one another.

Future studies should involve further and different methods of testing the drinking water quality in the water system to provide greater confidence in the results. This could involve testing in different seasons and triplicates of testing at each site. Accumulation of organic rich sediment may increase risks from saprozoic (environmental) pathogens such as *Legionella* and non-tuberculous mycobacteria (Ashbolt, 2015), if not also presenting an aesthetic issue of taste and odour in the water. Furthermore, testing to determine contamination occurring after collection at the water storage level should also be addressed (Hamzah et al., 2020). Communicating the possible issues and solutions around the unpleasant odor at the Nan Micho reservoir should also be discussed with the community. The nature of faecal pollution (i.e. human versus wildlife) and likely higher risk from human sources was not assessed, so a thorough Risk Assessment and further water testing is required to make a conclusive judgement. Overall, a Water Safety Plan (World Health Organization, 2012) would be a useful resource for the supporting organization and community to complete together to further identify potential contamination hazards and their management.

Chapter 5: Discussion and Conclusion

Although water, sanitation, and hygiene (WASH) are closely interconnected, this thesis focused on the supply of clean and safe water as it is arguably the foundation to effective WASH practices. The hardware and technical aspects of water systems is important, but of equal importance is the 'software' - the people behind it. This thesis intended to create a comprehensive understanding of the factors that are influencing the sustainability of a water system in a rural Haitian village.

The aims of this thesis were to:

1) Quantify the presence of *Escherichia coli* throughout the water system (Chapter 3)
2) Understand the experience of residents using a gravity-fed water system in rural Haiti (Chapter 4)
3) Determine what factors are influencing the sustainability of the gravity-fed water system (Chapter 4)

Summary of Findings

To evaluate microbial water quality and potential contamination throughout the system, Aquagenx CBT ® *E. coli* MPN Kits were used to test three water points from each of the five reservoirs. Some 27% (4/15 of taps were categorized as Safe by the WHO Drinking Water Guidelines, 27% (4/15) of water points tested were of Intermediate Risk, and 48% (7/15) were High Risk. Reasons for the contamination in some of the water points may be due to unsafe water retrieval practices, and with education may be mitigated easily. Disseminating this information to the community as an education aspect to preventing contamination of water sources when possible is an important piece long-term sustainability.

In some scenarios, sharing water quality information with communities who do not have the capacity to address the contamination concerns is arguably morally unethical. However, since HHI can work with the community to address the concerns, we found it acceptable to complete the testing. In addition, the testing was done alongside two community members, who were involved in both the testing and the reading of results. This built capacity in the community as these tests are simple and meant to the used in the field, the community members could do independently in the future.

Secondly, this research aimed to explore the experience and perceptions of residents using the gravity-based water system in a rural Haitian village. Though many frameworks for sustainability exist, this thesis used inductive methods to allow new theories and ideas to emerge from the interviews. The main findings from this objective were that the water system was important to the community, there is initiative to have more responsibility to maintain the water system - while still receiving external support from HHI, and there is a lack of community cohesion that may be influencing the degree to which the community can collectively maintain the water system. The findings were similar to other studies that explored the sustainability of water systems, but created a closer tie to the impact that community cohesion can impact the sustainability of a water system.

Significance of Findings

Though there are many frameworks to evaluate factors that may be influencing sustainability, they are not applicable to rural settings due to the differences in technology and service provision. This research emphasizes the importance of internal community characteristics in maintaining a water system and highlights the need for context specific approaches to community managed water systems.

It also provides insight into the use of Aquagenx CBT ® *E. coli* MPN Kits, an accessible and accurate microbial test used to evaluate contamination throughout the water system. The use of Aquagenx CBT E. coli test can be continued to be used by the community for continual evaluation and reporting of microbial water quality.

Methodological Considerations

Employing a CBPR approach, this project intended to avoid the 'ivory tower' aspect of research, acknowledging how the privilege of researchers may impact the power dynamic and the nature of the research. Working closely with community members, this project was conducted with all stakeholders being active part of the process, including research topic, data collection, and knowledge translation.

Qualitative description allows researchers to create a surface level summary of the data in order to create a comprehensive summary of results (Sandelowski, 2000). Using this method, a foundational understanding of the experience of residents using the water system could be gathered.

Regarding the water quality testing, the inability to conduct replicates of each site in addition to gaining insight of one point in time may not have produced an accurate representation of the water quality throughout the system.

Conclusion

In order to making access to safe drinking water a reality in rural/remote communities, governments, organizations, and experts must ensure that there is enough planning, implementation, and collaboration. Working with communities and understanding the various drivers and factors that impact the sustainability of a water system in its specific context is crucial in identifying ways to create stronger, more resilient communities through consistent access to clean and safe water.

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Appendix A: Community & Organization Report

TIMO WATER SYSTEM REPORT

PREPARED BY

Heather Nixdorff
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August 2019

BACKGROUND

This report was completed by Heather Nixdorff, a Master of Science student in the School of Public Health at the University of Alberta, Canada. She partnered with Haiti Health Initiative (HHI) to address concerns about sustainability in the water system in Timo, Haiti.

Located in the 10th Communal Section of Fond'Oies in Haiti's Western Department (Martial, 2019), the small community of Timo is situated in a mountainous valley of Southern Haiti, 65 kilometers (3-hour drive) from its capital, Port-au-Prince. The nearest city is Léogane - the epicenter of the 2010 earthquake. Access to the community is via a 3-kilometer hike (30 minutes) through the valley off the main road that runs through the district of Tom Gateau, the nearest town. Residents of Timo exist on less than $1 USD per day and are among the poorest people in Haiti (Martial, 2019).

Prior to the water system, residents retrieved water from surface streams and hand-dug wells. In 1994, Association of the Peasants of Fondwa (APF) built the initial water system scheme. In 2008, HHI expanded the water system with the help of the community. Today, the gravity-red water system consists of five reservoirs running to 52 taps, which serves over 1,000 people in the valley. The water is acquired through springs located high in the valley and are specific to this community.

Ethics approval for this project was given by the University of Alberta and the Ministry of Health in Haiti.

A functionality assessment and water quality testing for Escherichia coli using Aquagenx Compartment Bag Tests were also completed. Results are available upon request.

PROBLEM STATEMENT

There have been growing concerns regarding the sustainability of the system, being described by the organization as "a house with no windows." (Petit, 2017). The organization is also interested in installing an automatic chlorine dispenser as a means of centralized water treatment but would like to address management and sustainability concerns first.

OBJECTIVE & METHODS

In this study, the factors of sustainability in the water system were explored through understanding the experience of the residents using the water system in Timo.

This study used qualitative descriptive methods and was guided by a community-based participatory research (CBPR) framework. Using qualitative description allowed the researchers to stay close to the data and provide a straight description of what was said by participants (Sandelowski, 2000).

CBPR aims to equitably involve all partners in the research process, drawing on the strengths that each partner brings (Mayan, 2017). The elements of CBPR were fostered through establishing a research question that was important to the community and organization, and actively involving community members in the development and analysis of the project.

Interviews were completed with 22 residents of Timo who had experience with the water system. Participants were chosen based on their location in the reservoir lines and ability to be interviewed.

Interviews were recorded in Creole by a local research assistant that had been trained in qualitative methods. The interviews were translated into English and transcribed. Analysis was used using NVivo software.

In the interviews, questions about experience with the current water system and water system management were asked.

FINDINGS

Three main themes were found in the interviews that related to the sustainability of the water system. Recommendations based on literature are included.

Appreciation of Water System

Overall, the water system in Timo has positively impacted the residents in Timo. It has decreased concerns about contamination of water, decreased risk of injury when retrieving water, and increased convenience/time saving.

Initiative to Maintain

There are many signs of desire to maintain the water system. Many residents spoke about how they did not want to have to wait for help from Haiti Health Initiative for the minor repairs and that there could be ways of raising money in order to purchase materials needed to maintain/repair the water system.

There were many requests for Haiti Health Initiative to help more with training and education for maintenance of water system.

Recommendations:

- Meet with community and water committee to determine the level of external support desired (materials, finances)
- Complete further training with water committee, including training for basic repairs. Provide formal training certificate
- Provide community level education about water system importance and everyday maintenance
- Implement accountability reports for water committee to be sent to HHI

Lack of Community Cohesion

There is a perceived lack of support and communication in maintaining the water system in the community, regarding both labor and monetary contributions. Water access has been impacted by frustration and not getting along with neighbors.

Recommendations:

- Increase transparency about finances regarding payment of water committee and where money is allocated
- Enhance communication, particularly about responsibilities (who is in the water committee, who is responsible for what, communication between organizations in area)

ADDITIONAL INFORMATION

In addition to the identified themes and recommendations listed above, this report includes participant reported reasons for system malfunction, suggestions to improve water access, and a summary of community requests.

Reasons for System Malfunction:

Intentional

- Slashing pipe using machete or other objects
- Breaking control valves

Unintentional:

- Pipe being punctured due to gardening picks
- Animals stepping on pipe
- Rocks falling on pipe

Suggestions to improve water access:

- Have a community meeting, including water committee and community leader to collaborate on what is working, what isn't, and how to move forward
- Put all (pressure reducing and control) valves in a locked box and give key to one person. Person to be living near the head of reservoir with the key
- Create system for money to be saved that the community contributes for purchases (locks, covers, etc.)
- Encourage people to pay for repairs in the water system if they were the one who damaged it

Summary of Community Requests:

- Education about the importance of the water system and how to maintain the system
- Training for water master and water committee and community" (i.e. cleaning, repair, communication, system expansion)
- Financial assistance for system maintenance and expansion (i.e. completing cement posts, repairing of pipes, catchment cover Further water testing
- Water treatment (automatic chlorine dispenser in community reservoirs/community level, household level)
- Mean to decrease water contamination (public latrines, buckets with faucets (Gayden Dlo))

Appendix B: Participant Information Form (English)

INFORMATION LETTER & CONSENT FORM

Factors of Sustainability of a Gravity-Based Water System in Rural Haiti

Researcher:

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President of National Bioethics Committee:

Dr. Gerald Lerebours
President
c / o AMH
29 Avenue de la Ligue Féminine,
Front Avenue du Travail
Port au Prince, Haiti

Background

You are being asked to participate in this study because you are a resident of Timo who has access to a tap in the water system. This study is happening to better understand the experience of Timo residents using the water system. Other residents of Timo who have access to a tap will also be asked to participate by Vernet (community leader). Benefits of this study are to understand how to have a better functioning and longer lasting water system in Timo.

Purpose

The purpose of my research project is to better understand the experience of the people that have access to a water tap in Timo. My project will help understand how to make the water system in Timo work better and last longer.

The results of this study will be used in support of my graduate studies thesis in Canada.

Study Procedures

Interviews can happen in either your house or the community center.

The time to complete an interview will be approximately 30 minutes to an hour. You will only have to complete one interview.

Interviews will be recorded and typed out on a computer.

Benefits

There will be no direct benefit from participating in this study. I hope that the information I get from this study will help make the water system work better in Timo.

Risks

It is possible that you may feel stress when talking about the water system. It is not anticipated that this study will harm you in any other way. If you are worried, you may speak to the researcher (Heather).

Confidentiality

Information from this study will be used for my graduate research thesis and conference presentations. You will not be personally identified. The recording of this interview and all other documents will be kept in a locked box, in a locked room in the community center. After the interview is typed out on the computer, no one will be able to link your name to this interview. The researcher (Heather) will be the only one who has access to the information.

Study data, including personal information about you will be securely stored for 5 years after the study is over, at which time it will be destroyed.

You will not receive a copy of this report. A summary report will be placed in the community center.

Incentive

I appreciate you taking part of my study. You will receive a flashlight for your participation in this study.

Voluntary Participation

You have the right to refuse this invitation to participate or to refuse to answer any of the questions asked during the interview. You are also free to stop the interview at anytime or request that we withdraw your information (transcripts, audio recording) up until the day that the researcher leaves the community, which will be approximately on June 5, 2018.

Withdrawal from the Study

If you choose to withdraw from the study, the audio tape and any transcripts that have been made will be destroyed immediately. You are free to withdraw up until the researcher leaves the community.

The University of Alberta Research Ethics Board has approved this research study.

Thank you very much for taking part in this study.

The plan for this study has been reviewed by a Research Ethics Board at the University of Alberta. If you have questions about your rights or how research should be conducted, you can call (780) 492-2615, or email reoffice@ualberta.ca

This office is independent of the researchers.

Appendix C: Participant Information Form (Creole)

LÒT ENFÒMASYON AK FÒM KONSANTMAN

Faktè nan Sustainability nan yon sistèm Dlo Gravite ki baze sou nan Riral Ayiti

Chèchè:

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Prezidan Komite Nasyonal pou Byoenetik:

Dr. Gerald Lerebours
President
c / o AMH
29 Avenue de la Ligue Féminine,
Front Avenue du Travail
Port au Prince, Haiti

<u>Istorik</u>

Yo mande w patisipe nan etid sa a paske ou se yon rezidan Timo ki gen aksè a yon tiyo nan sistèm dlo a. Etid sa a ap pase pou pi byen konprann eksperyans rezidan Timo yo lè l sèvi avèk sistèm dlo a. Lòt moun ki rete nan Timo ki gen aksè a yon tiyo pral mande tou yo patisipe nan Vernet (lidè kominote a). Benefis etid sa a se pou konprann kijan pou gen yon pi bon sistèm fonksyònman ak pi long ki dire lontan nan Timo.

<u>Objektif</u>

Rezon ki fè pwojè rechèch mwen an se pi byen konprann eksperyans moun ki gen aksè a yon tiyo dlo nan Timo. Pwojè mwen pral ede konprann kijan pou fè sistèm dlo a nan Timo travay pi byen ak dire pi lontan.

Rezilta etid sa a pral itilize nan sipò nan tèz syans gradye mwen nan Kanada.

Pwosedi etid yo

Entèvyou ka rive nan swa kay ou oswa sant kominotè a.

Tan pou konplete yon entèvyou pral apeprè 30 minit pou yon èdtan. Ou pral sèlman gen pou konplete yon sèl entèvyou.

Entèvyou yo pral anrejistre ak tape soti sou yon òdinatè.

Benefis

P ap gen okenn avantaj dirèk nan k ap patisipe nan etid sa a. Mwen espere ke enfòmasyon mwen jwenn nan etid sa a ap ede fè sistèm dlo a travay pi byen nan Timo.

Risk

Li posib ke ou ka santi estrès lè w ap pale de sistèm dlo a. Li pa antisipe ke etid sa a pral mal ou nan nenpòt lòt fason. Si ou enkyete, ou ka pale ak chèchè a (Heather).

Konfidansyalite

Yo pral itilize enfòmasyon ki nan etid sa a pou tèz rechèch gradye ak prezantasyon konferans mwen. Ou pa pral pèsonèlman idantifye. Yo pral kenbe anrejistreman entèvyou sa a ak tout lòt dokiman yo nan yon bwat fèmen, nan yon chanm fèmen nan sant kominotè a. Apre entèvyou a se tape sou òdinatè a, pa gen moun ki pral kapab konekte non ou nan entèvyou sa a. Chèchè a (Heather) pral youn nan sèlman ki gen aksè a enfòmasyon an.

Etid done, ki gen ladan enfòmasyon pèsonèl sou ou yo pral byen estoke pou 5 ane apre etid la se sou, nan ki tan li pral detwi.

Ou pap resevwa yon kopi rapò sa a. Y ap mete yon rapò rezime nan sant kominotè a.

Ankouraje

Mwen apresye ou pran yon pati nan etid mwen an. Ou pral resevwa yon flach pou patisipasyon ou nan etid sa a.

Patisipasyon Volontè

Ou gen dwa pou refize envitasyon sa a pou patisipe oswa pou refize reponn nenpòt nan kesyon yo mande pandan entèvyou a. Ou menm tou yo gratis yo sispann entèvyou a nan nenpòt ki lè oswa mande pou nou anile enfòmasyon ou (relve nòt, anrejistreman odyo) jiska jou a ki chèchè a kite kominote a, ki pral apeprè sou 5 jen, 2018.

Retrè soti nan etid la

Si w chwazi pou w retire nan etid la, kasèt odyo ak nenpòt ki transkripsyon ki fèt yo pral detwi imedyatman. Ou lib pou ou retire jiskaske chèchè a kite kominote

Inivèsite Alberta Rechèch Etik Komisyon an apwouve etid rechèch sa a.

Mèsi anpil pou w patisipe nan etid sa a.

Te plan pou etid sa a revize pa yon Komite Rechèch Etik nan University of Alberta. Si ou gen kesyon sou dwa ou yo oswa ki jan yo ta dwe fè rechèch, ou ka rele (780) 492-2615, oswa imèl reoffice@ualberta.ca

Biwo sa a endepandan de chèchè yo

Appendix D: Participant Consent Form (English)

CONSENT FORM

Factors of Sustainability of a Gravity-Based Water System in Rural Haiti

Heather Nixdorff

hnixdorf@ualberta.ca

University of Alberta

Please circle the answers:

Do you understand that you have been asked to be in a class project research study?	Yes	No
Has the Information Sheet been read to you?	Yes	No
Do you understand the benefits and risks involved in taking part in this study?	Yes	No
Have you had an opportunity to ask questions and discuss this study?	Yes	No
Do you understand that you can stop taking part at any point during the interview?	Yes	No
Do you understand that you can withdraw at any time during the data collection part of the study and that any comments that you provided up to that point will not be used?	Yes	No
Has confidentiality been explained to you?	Yes	No
Do you understand who will have access to the data collected?	Yes	No
Do you understand that the interviews will be audio recorded and typed out?	Yes	No
Do you understand that you have up until the end of the day of your interview to withdraw what you have shared in the interview?	Yes	No

Verbal consent:

Information form has been read to participant

_____________________________ _____________________

Signature of Interviewer Date (dd/mm/yy)

Participant has given verbal consent to participate in this study

_____________________________ _____________

Signature of Interviewer Date (dd/mm/yy)

Appendix E: Participant Consent Form (Creole)

FÒM KONSANTMAN

Tit etid: Faktè nan Sustainability nan yon sistèm dlo gravite ki baze nan Riral Ayiti

Heather Nixdorff

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University of Alberta

Tanpri sèk repons yo:

Èske ou konprann ke ou te mande pou yo nan yon etid rechèch pwojè klas la?	Wi Non
Èske li te fè ou konnen enfòmasyon an?	Wi Non
Èske w konprann benefis ak risk ki genyen nan patisipe nan etid sa a?	Wi Non
Eske ou te gen yon opòtinite pou poze kesyon epi diskite etid sa a?	Wi Non
Èske ou konprann ke ou ka sispann patisipe nan nenpòt pwen pandan entèvyou a?	Wi Non
Èske ou konprann ke ou ka retire nenpòt ki lè pandan koleksyon an pati nan etid la e ke nenpòt kòmantè ke ou bay jiska pwen sa pa pral itilize?	Wi Non
Èske yo te eksplike ou konfidansyalite?	Wi Non
Èske ou konprann ki moun ki pral gen aksè a done yo kolekte?	Wi Non
Èske ou konprann ke entèvyou yo pral odyo anrejistre ak tape soti?	Wi Non
Èske ou konprann ke ou gen jiska la fen jou entèvyou ou a retire sa ou te pataje nan entèvyou a?	Wi Non

<u>Konsantman vèbal:</u>

Fòm enfòmasyon yo te li pou patisipan

______________________________ ______________________

Siyati dat entèvyou a (dd / mm / yy)

Patisipan te bay konsantman vèbal pou patisipe nan etid sa a

______________________________ ______________

Siyati dat entèvyou a (dd / mm / yy)

Appendix F : Semi-Structured Interview Guide

How many people are living in your home?

What water sources do you use?

For what purpose?

How do you conserve water?

When it rains, how do you retrieve water?

Who is responsible to retrieve water in your home?

Before the water system was installed, how did you retrieve water?

How did that impact your life?

What do you think about the water system?

How has it impacted your health?

If repairs are needed, why do those things happen?

Who is responsible for repairs?

Who is responsible for cleaning?

Why are those people (for repairs or cleaning) responsible?

In your opinion, what role does the community play in the water system?

In your opinion, what role does HHI play in the water system?

When the earthquake happened, how did you retrieve water?

How did that impact your life?

Do you have a latrine in your home?

How often do you use it?

When you are working, where do you relieve yourself?

Is there anything else you would like to tell me?