Ensuring Safe Drinking Water for the Northern Corridor of Haiti Through Expanded Testing Services

by
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ABSTRACT

Due to the lack of potable piped water, drinking water access is a concern in Haiti. Families often gather water for household use from private wells, springs, and rivers. These local water sources are often of unknown or poor quality due to poor sanitation. Public health events such as the cholera outbreak of 2010 demonstrated the vulnerability of the Haitian populations to water contamination and government capability to address these issues have been weak. Attempts have been made to reduce the prevalence of waterborne disease by establishing for-profit kiosks that sell treated drinking water treatment. However, kiosk water is not regulated or routinely tested. There is some evidence that it does not meet drinking water standards, leading to concerns about waterborne disease. If kiosk water testing is implemented, the costs must be supported by water vendors. These costs may not be feasible due to Haitian economic conditions and reliance on imported products that often disrupt the financial sustainability of businesses.

This dissertation examines challenges to providing safe drinking water in the Northern Corridor of Haiti and evaluates potential improvements. This research assessed, first, the main factors that hinder access to water testing and that lead to high cholera infection rates among communities in the Northern Corridor. Second, the quality of drinking water sold at for-profit kiosks was appraised for the main urban municipalities in the region, and the kiosk owners' willingness to periodically test the drinking water sold and pay for testing was assessed. Finally, a rigorous assessment of financial sustainability of a university-based drinking water laboratory in the Northern Corridor of Haiti was done by calculating internal rate of return (IRR) and net present value (NPV) following some risk assessments.

In the first study, correlation, regression, and travel time analysis were performed to identify community-level factors that are associated with cholera infection rate and prevent access

to a new water testing laboratory in Limonade. Poor road conditions, high elevation, mountainous terrain, and limited transportation options lead to long travel times up to 5.7 minutes/km between remote communities and the laboratory. The presence of springs in communities had a significant positive correlation with cholera infection rate at the community level. However, socioeconomic factors had no significant correlation with cholera infection rate. While the new laboratory will play a vital role in promoting safe drinking water for the cities near Limonade, these findings demonstrate that many remote communities will not be served by the lab. There is a need to establish small water testing and treatment facilities in these vulnerable remote areas to limit the spread of waterborne diseases.

In the second study, surveys of for-profit water vending kiosks were conducted. Water samples were collected from selected kiosks and the kiosk operators were surveyed about their water treatment practices and willingness to participate in a water testing program. The samples were tested for total coliforms, *E. coli*, residual chlorine, pH, and conductivity. Third, survey data were analyzed using descriptive statistics and logistic regressions to assess the water vendors' willingness to test the kiosk water, determine the amount they would be willing to pay for testing, and identify the best incentives to motivate kiosk owners to pay for water testing services. Water samples from downtown of Cap-Haitian and its peripheral districts contained high levels of *E. coli* exposing consumers to high health-risk. In addition, the residual chlorine level was below both WHO and DINEPA standards, which could explain the presence of coliforms. Further, many kiosk owners do not properly maintain their facilities. Fifty percent of kiosk owners did not remember the last time the water treatment equipment was maintained and around one quarter performed maintenance once a year. Survey results also indicated that many drinking water vendors would only be willing to pay for regular testing if it was mandatory. These results indicate the importance of drinking water regulations and enforcement and the need to increase public awareness of drinking water safety in the Northern Corridor of Haiti.

In the final study, the financial sustainability of a university-based drinking water laboratory in the Northern Corridor was assessed through sensitivity analysis of a range of factors that may affect laboratory revenues. Profitability was determined by calculating the internal rate of return (IRR). This analysis showed that the laboratory must perform microbiological testing for an average of five samples per day to reach financial sustainability. Price-based incentives for new clients have relatively small impacts on profitability whereas lowering the number of daily samples performed has a high impact on the projected IRR. Finally, international and Haitian inflation could affect the sustainability of the drinking water laboratory. These economic factors will be among the key drivers of laboratory operating costs and subsequent financial viability. A relevant marketing plan must be designed to the demand for water testing and price-based incentives will be the best strategy to keep demand high.

This dissertation identified relevant strategies that will improve access to safe drinking water for households in the Northern Corridor of Haiti. Further studies are needed to identify municipalities with the appropriate infrastructure and willingness of local governments to implement drinking water testing and treatment. Additionally, private kiosk surveillance must be mandated by public health authorities and drinking water regulators to ensure safe water for consumers. DINEPA, the Ministry of Public Health, and the Ministry of Commerce should promote regular maintenance and optimum water treatment methods at the kiosk level. For that, kiosk water maintenance must be regulated followed by law enforcement that should be established for all.

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ANOVA	: Analysis of Variance
AVANSE	: Appui à la valorisation du potentiel Agricole Nord pour la sécurité environnementale et économique/ Support for the development of the North Agricultural potential for environmental and economic resiliency.
AU	: Auburn University
CFR	: Case fatality rate
CH	: Cap-Haitian
CHCL	: Campus Henry Christophe de Limonade
CNIGS	: Centre national de l'information géospatiale/ National Center for Geospatial Information
CR	: Consumers' requirements
D	: Distance
DAI	: Development alternatives Inc.
DDAN	: Direction départementale agricole du Nord/ North Agricultural Departmental Directorate
DGS	: Daily gallons sold
DIM	: Differential importance measure
DINEPA	: Direction nationale de l'eau potable et de l'assainissement/ National Directorate of Drinking Water and Sanitation

DPD : *N*-diethyl-*p*-phenylenediamine

DSPN : Direction de la santé publique du Nord/North Directorate of Public Health

E : Elevation

EPA : Environmental programmatic assessment

FC : Fixed costs

GPS : Global positioning system

IDB : Inter-American development Bank

IDLS : Indicator of depravation in living standards

IHSI : Institut Haïtien de statistique et d’informatique/Haitian Institute of Statistics and Informatics

IMP : Indicator of monetary poverty

IRR : Internal rate of return

MINUSTHA : Mission des Nations Unies pour la stabilisation d’Haïti

MPN : Most probable Numbers

MSPP : Ministre de la santé publique et de la population/Ministry of Public Health of Populations

NGO : Non-gouvernemental Organizations

NPV : Net Present Value

OREPA : Office Régionale de l'eau potable et de l'assainissement/Regional Bureau of Drinking Water and Sanitation

P : Probability

R : Cash flow

RC : Road conditions

RO : Reverse Osmosis

STATA : Statistical software

T : Time

TDS : Total dissolved solid

TM : Testing mandatory

TX : Texas

UEH : Université d’Etat d’Haïti/State University of Haiti

USAID : United States agency for international development

USD : US dollar

UV : Ultra-violet

WATS : Willingness to adopt transportation services

WATSAN : Water and sanitation

WHO : World Health Organization

WTA : Willingness to accept

WTP : Willingness to pay

CHAPTER ONE: INTRODUCTION

1.1. Background and overview

The pathogenic organisms transmitted by drinking water are mainly of fecal origin. Since pioneering epidemiologist John Snow established that cholera was waterborne in the 1850s, scientists have gained a solid understanding of the transmission of various pathogens that cause diarrhea and other illnesses via drinking water (Ashbolt et al., 2001; Hunter et al., 2002; Paneth et al., 1998; and Hunter et al., 2002 cited by Ashbolt, 2004a). Many health problems have been traced to ineffective water treatment, polluted water sources, and a lack of sanitation and hygiene. This has led to an estimated 3.4 million deaths due to waterborne illness (Li, 2011). Since many people in developing countries have limited access to treated water and even fewer to water testing laboratory services, efforts should be made to establish both water treatment systems and water testing programs (Peeling & Mabey, 2010). Both water treatment and testing services are crucial in ensuring safe drinking water for households.

Efforts to improve access to safe drinking water in developing countries must consider affordability and take measures to reduce costs, such as differentiated pricing, targeted aid programs, and cross-subsidy systems. Countries that do little to address affordability are likely to impose a high burden of water expenses on the most vulnerable people (Smets, 2009). The high cost of safe water may be driven by economic factors or inaccessibility to appropriate technologies for efficient water treatment and testing. Infrastructure to make safe drinking water readily available is needed in both urban and remote areas.

1.1.1. Haitian drinking water context

Numerous households in Haiti do not have access to clean and safe water and are at risk from outbreaks of waterborne bacterial infections (Tauxe, 1995; Ashbolt, 2004; Nabeela et al., 2014). Close to 70% of Haitian households have no direct access to potable water (Varma et al., 2008). Many households do not have a piped water supply for needs such as laundry, bathing, and cooking. Shallow groundwater is the main water source followed by rivers, springs, lakes, and lagoons that often carry infectious disease-causing organisms such as bacteria, viruses, and parasites (Schram & Wampler, 2018) James & Joyce, 2004). Due to poor infrastructure, only 2% to 8% of Haitian homes have household water connections or piped water. The lack of supply has increased the prevalence of pathogenic microbes in the environment (Varma et al., 2008). For instance, *Vibrio cholera* in raw sewage from United Nations peacekeeping troops from Nepal was the source of a cholera epidemic. It was paired with a typhoid outbreak also caused by fecal contaminants (Barzilay et al., 2013; Frerichs et al., 2012; Escamilla et al., 2013; Cabral, 2010; Gwimbi, 2011).

In addition, rapid urbanization and poor sanitation in the rural-urban fringe has changed the pattern of disease outbreaks. In the Northern Corridor, which includes the second largest Haitian metropolitan area of Cap-Haitian, much of the housing is unfinished and lacks sanitation and piped water (Iannotti et al., 2014). The region also lacks drinking water testing services. Therefore, waterborne illness is one of the leading causes of health care expenses for household members living in downtown Cap-Haitian and its surrounded slums where frequent floods have been paired with poor sanitation (Wu et al., 2014; Swift, 2015). Additionally, poor drainage has fostered outbreaks of diseases, particularly among low income households (Lungová, 2015).

1.1.2. Drinking water sources

In suburban and remote communities in the Northern Corridor, inhabitants have mainly sourced their drinking water from unprotected springs or from rivers and have faced a high risk of exposure to waterborne diseases (Wampler & Sisson, 2011; Galada et al., 2014). This is due to the inability of the Haitian government to improve water and sanitation services (Lantagne et al., 2006). Many Haitians assume that water emerging from the ground at a spring is clean and safe to drink, especially in rural areas where industrial contamination is not present (Wampler & Sisson, 2011b). However, during the cholera epidemic in 2012, the disease was prevalent throughout the country, even in remote areas. On the other hand, many rural Haitians know that drinking untreated water from streams and rivers is not safe.

The cholera epidemic fostered a change in drinking water sources in cities. Currently, the primary drinking water source in cities such as Cap-Haitian is treated water sold at for-profit kiosks, small stores dispensing water in one- or five-gallon quantities. Other sources included treated water sold in single-serve plastic bags, bottled water, and public and private wells (Martinez, 2019a). All these drinking water types primarily source their raw water from groundwater. During floods, groundwater may be affected by transported microbial contaminants and must be treated appropriately (Rivera-Núñez et al., 2018a). The government agency responsible for drinking water infrastructure, Haiti’s Direction Nationale de l’Eau Potable et d’Assainissement (DINEPA), has been unable to supply urban households with safe drinking water, increasing the health-risk from waterborne diseases in cities. In these communities, household members noted a lack of availability of at-home water treatment products (Maleki et al., 2020). Therefore, Haitians have continuously sought ways to reduce the waterborne health risk.

1.1.3. Kiosk water treatment

To reduce drinking water concerns driven by endemic pathogens and exacerbated by the cholera outbreak in 2010, private-sector kiosks were promoted as the best strategy to mitigate waterborne disease risk (IFC-World-Bank, 2022). These water facilities typically operate as franchises of providers sourcing water from wells and treating it using reverse osmosis filtration. While kiosks are an improvement over untreated water, there is concern that they may still pose a health risk. For instance, drinking water collected from for-profit kiosks in Port-au-Prince tested positive for *E. coli* (Patrick et al., 2017; Peter et al., 2020). Drinking water that tests positive for *E. coli* does not meet World Health Organization (WHO) standards, and those who consume this water suffer from typhoid fever (Farooqui et al., 2009). Even though most households purchase treated water from kiosks, a significant number of typhoid cases are recorded in Cap-Haitian and the surrounding districts (Chierici & Voltaire, 2016). Therefore, kiosk water treatment facilities have not always supplied safe drinking water. This may be due to improper or infrequent maintenance of the drinking water treatment equipment used by kiosks. Further, the Northern Corridor of Haiti lacks drinking water testing laboratories and regulation of kiosk maintenance and quality (Franz et al., 2014; Prest et al., 2016; Sangwan et al., 2021). There is a need to improve and monitor the drinking water quality for kiosks in Cap-Haitian and surrounding municipalities.

1.1.4. Kiosk monitoring

To ensure that for-profit water kiosks supply safe drinking water, regular drinking water monitoring is an important strategy. The monitoring of drinking water quality should aim to evaluate equipment, such as filters and reverse osmosis systems, and perform diagnostic water quality testing to evaluate disinfection level and indicators of microbial contaminants (American Water Works Associations, 2002). The establishment of drinking water kiosk surveillance may be an appropriate strategy to ensure good maintenance. Moreover, routine drinking water testing is key to ensure the hygiene and safety of water sold by kiosks (Hashim & Yusop, 2016). To address this last need, a drinking water testing laboratory was established on the Campus Henry Christophe of Limonade (CHCL) funded by the US Agency for International Development (USAID) and technically supported by Auburn University. The goals of the lab are to lead academic research, to provide water testing services to the communities including drinking water kiosks, and to support the Ministry of Public Health/Ministère de la Santé Publique et de la population (MSPP) and DINEPA by providing training for water resources technicians and engineers.

1.1.5. Sustainable laboratory operation

To guarantee the sustainable operation of the drinking water laboratory, private kiosk owners, who are expected to be the main clients, will need to send water samples for regular testing. We assume many factors could be crucial to motivate these entrepreneurs to participate in testing such as travel time to the central laboratory and water testing fees. To sustainably manage the drinking water testing laboratory over a five-year period of operation, the laboratory management must anticipate income from testing fees, kiosk owners' demand and willingness-to-pay, and the potential effects of broader economic changes (Gafli & Fauzi, 2019; Onyeonoru, 2005; Ivanova et al., 2000).

The consumers' preference principle states that if the quality of a good or service is a relative term, defined as a set of product or service characteristics and the product's ability to satisfy the consumer, choice is based on the consumers' awareness of the intrinsic value (Ismaiel et al., 2014). Based on this, we assume that the demand for water testing from kiosk owners should be correlated to the consumers' awareness of the potential health risk of unsafe water. However, the low education levels of the population of the Northern Corridor of Haiti limits the consumers' awareness of these issues. Further, outreach to provide information to water consumers may impact water testing demand.

1.2. Objectives

The challenges to providing safe drinking water in Haiti include the prevalence of unsafe water sources in cities and remote areas, uncertainty about the safety of water from unregulated kiosks, a lack of financially sustainable water testing laboratories, and limited understanding of the attitudes of kiosk owners and water consumers. This dissertation seeks to address the drinking water concerns in the Northern Corridor of Haiti and provide insight into the safe and sustainable operation of drinking water systems in developing countries. This research addresses the following knowledge gaps: (i) determining the community-level factors that limit access to safe drinking water in the Northern Corridor, (ii) identifying contaminants in drinking water from kiosks that cause illness of consumers; and finally, (iii) examining the economic factors that may prevent the sustainability of laboratory services for kiosks. This dissertation examines the Haitian drinking water system to identify problems and suggest potential solutions. It has the following objectives:

i. Objective 1: Assess the community-level factors contributing to waterborne disease risk, such as cholera, and its spread throughout the populations in the Northern Corridor and identify the main factors that could constrain access to the drinking water testing laboratory at CHCL.

ii. Objective 2: Assess the quality of drinking water sold at for-profit kiosk water facilities in the municipalities of Cap-Haitian, Limonade and Quartier Morin and the kiosk owners' willingness level to routinely test the drinking water sold.

iii. Objective 3: Determine the main factors that will affect the economic sustainability of the drinking water laboratory established at CHCL.

1.3. Hypotheses

We hypothesize that:

i. The presence of springs is the main community-level factor contributing to the risk of cholera across the Northern Corridor of Haiti.

ii. Due to the long travel time to CHCL, it will not be feasible for remote communities in the Northern Corridor to utilize laboratory-based water testing services.

iii. Drinking water sold at kiosks in Cap-Haitian and surrounding municipalities has high health-risk for the households.

iv. Poor drinking water quality from kiosks is due to improper or irregular maintenance of the water treatment facilities.

v. Haitian inflation and inflation on imported supplies are the highest risk factors for the sustainability of the drinking water testing laboratory.

1.4. Organization of the dissertation

This dissertation is divided into five chapters that describe, assess, illustrate, and present the steps to test the hypotheses and accomplish the research objectives. Following this introductory chapter, Chapter Two: *Community-Level Factors Contributing to Cholera Infection and Water Testing Access in the Northern Corridor of Haiti*, assesses the community-level factors that increase cholera risk and limit access to drinking water testing services at CHCL. Chapter Three: *Kiosk water quality assessment and for-profit kiosk owners' willingness to pay for drinking water testing in Northern of Haiti*, analyzes the water quality of samples from kiosks and assesses the willingness of water vendors to pay for regular water testing. Based on the kiosk operations observed, best strategies are proposed to improve the safety of kiosk water. Chapter Four: *Pricing Drinking Water Testing in Northern Haiti: Financial Sensitivity to Operating Costs, User Demand, and Economic Conditions,* simulates the profitability of the laboratory based on the water testing demand from different categories of clients. The effect of economic factors such as international chemical price index and Haitian inflation were analyzed to estimate potential effects on profitability. Chapter Five: *Conclusions and Impact* summarizes the major findings and impact of this dissertation and highlights topics for future studies to implement drinking water regulations for the private sector and technical support needed by for-profit kiosk owners to supply safe water to consumers.

CHAPTER TWO: COMMUNITY-LEVEL FACTORS CONTRIBUTING TO CHOLERA INFECTION AND WATER TESTING ACCESS IN THE NORTHERN CORRIDOR OF HAITI

Abstract

Vibrio cholera, the bacteria that cause cholera, is endemic in Haiti with a presence in both cities and remote areas. Improved access to drinking water testing and treatment in remote areas may reduce the impact of the disease. This case study uses correlation and regression analysis to identify the main factors that hinder access to water testing and that lead to high cholera infection rates among communities in the Northern Corridor of Haiti. Poor road conditions, mountainous terrain, and limited transportation options lead to high travel times up to 5.7 min/km between remote communities and drinking water testing facilities. The presence of springs in a community has a significant positive correlation with cholera infection rates in the Northern Corridor. However, socioeconomic factors had no significant correlation with cholera infection rate. The results of this study will be used to plan the implementation of a new drinking water testing laboratory near the city of Cap-Haitian and other programs for vulnerable remote areas.

2.1. Introduction

Vibrio cholera appeared in Haiti for the first time in recent history in October 2010. Recent epidemiological and molecular-genetic evidence indicate that United Nations peacekeeping troops from Nepal were the source (Frerichs et al., 2012). The epidemic progressed rapidly, affecting all ten departments in the country, including the deepest remote areas within one month (Barzilay et al., 2013). The presence of *V. cholera* throughout the country is a concern because it is a causative agent of waterborne and foodborne cholera illness. Cases of cholera in Haiti have declined gradually from a peak of 352,000 in 2011 to 720 in 2019 (Ministre Santé Publique et de la Population, 2020).

It has been demonstrated that *V. cholera* may occur in all media including soil, water, and air (Feachem et al., 1981), but it most often causes disease when transmitted through water. In water, it is present in rivers, lakes, coastal waters, springs, and wastewater according to an assessment in Nigeria over both dry and wet seasons (Okafo et al., 2003). Therefore, *V. cholera* from the 2010 Haiti outbreak could have reached many water bodies (Alam et al., 2014), increasing the risk of exposure for Haitians using these water sources for drinking, cleaning, and bathing, recreation, and harvesting seafood. Additionally, irrigation with water infected by *V. cholera* can spread the disease when agricultural products are transported to markets (Okafo et al., 2003). Further research confirmed the presence of *V. cholerae* O1 and *V. cholerae* non-O1/O139 at rivers and estuaries sites in the southern part of the country (Alam et al., 2014). Due to a lack of sanitation facilities in many rural areas of Haiti, there is a risk of cholera exposure from the use of water in rivers, lakes, and springs without prior treatment. Fecal water contamination is an issue in nearly all water sources in Haiti due to poor hygienic conditions and low awareness of risks (Eisenberg et al., 2013).

To address the cholera outbreak and prevent future outbreaks, the Haitian government and non-governmental organizations acted to increase access to safe drinking water. As part of the response to the October 2010 cholera outbreak, the Government of Haiti, and these agencies-initiated country-wide efforts focusing on hygiene promotion and access to treated water. These efforts included chlorination of public drinking water systems and mass free distribution of water treatment products for household water for those people unable to access piped chlorinated water (Patrick et al., 2013). During the first year of the cholera response, it is estimated that over 100 million water purification tablets were distributed (Rinaldo et al., 2012).

Evaluations of the national cholera outbreak response indicate underreporting of cases particularly in remote areas (Page et al., 2015). Very remote areas were severely affected by the outbreak, in terms of both number of cases (high attack rates) and diarrhea-related deaths with high case fatality rate (CFR). This led to extremely high mortality rate estimates which suggest up to 5% of the populations in these areas had died during the first months of the epidemic (Page et al., 2015). Both drinking water and water used for household purposes may be a vector for cholera transmission (Lipp et al., 2002). In the rural area of Artibonite, sources of water used for household purposes (washing dishes, cooking, and bathing) varied widely with 50% of respondents using surface water sources such as rivers and lakes for dishes and cooking and 60% using surface water for bathing (Patrick et al., 2013a). In rural areas, the presence of animals around springs and other water sources increases the risks of exposure to waterborne disease. In some places around Gonaives, a multivariate analysis indicated eating meals outside the home, owning pigs, washing dishes, bathing, and sharing latrines are the strongest and most significant risk factors of cholera infection (Grandesso et al., 2014).

Rural communities may also be at higher risk of waterborne disease due to their socioeconomic status. Analysis of household-level risk factors in Haiti found that moderate to severe hunger were significantly associated with reported history of cholera in the household (Richterman et al., 2019). Looking more broadly at health outcomes, an incremental increase in education level leads to a statistically significant reduction in the incidence of childhood mortality in Haiti (Gordon, 2009). Higher income is also associated with lower infant mortality (Bryan & Kandulu, 2009; Marmot, 2002), childhood morbidity (Gordon, 2009) and overall health (Lindahl, 2005). Studies of individuals and households in Haiti indicate that water sources used and socioeconomic status influence waterborne illness risk, but community-level factors have not been investigated.

To reduce the prevalence of waterborne disease outbreaks including cholera in remote areas, there is a need to increase the awareness of households of waterborne diseases and increase both the treatment of community water sources and the acceptability of household water treatment and safe storage (Rinaldo et al., 2012). Lessons learned in other settings indicate that a combined approach involving partnerships between government, NGOs, and the private sector holds the most promise for scaling-up programs to enhance awareness of cholera prevention in remote areas, and a key aspect of these programs is access to water testing (Ramachandran & Walz, 2015). Frequent water testing will allow households to be confident in the safety of treated water through on-site testing for fecal contamination or testing of free chlorine levels to verify proper disinfection. To increase access to water testing in the Northern Corridor of Haiti, a drinking water testing laboratory is being established at the State University of Haiti/Campus Henri Christophe-Limonade (CHCL) through a partnership with Auburn University and the United States Agency for International Development (USAID).

Even with the water testing laboratory at CHCL, many communities in the Northern Corridor may still lack access to water testing services. Water samples for microbiological testing to detect fecal contamination, which indicates vulnerability to outbreaks of waterborne diseases including cholera, must be transported to the laboratory on ice within eight hours after collection (Environmental Protection Agency, 2016). Additionally, poor road conditions, limited transportation options, adverse weather, and other conditions may create uncertainty in travel time on arterial road networks from rural areas (Sekhar et al., 2012) to Limonade, the site of the central water quality testing laboratory.

Field technicians with the National Directorate of Drinking Water and Sanitation/Direction Nationale de l'Eau Potable et de l'Assainissement (DINEPA-Haiti) have noted that the high temperatures and long times required to travel short distances in Haiti make it difficult to comply with published sampling protocols. Poor transportation in rural areas has also resulted in low economic activity, productivity, and income (Tunde & Adeniyi, 2012) which may further hinder the ability of a community to access safe, treated water.

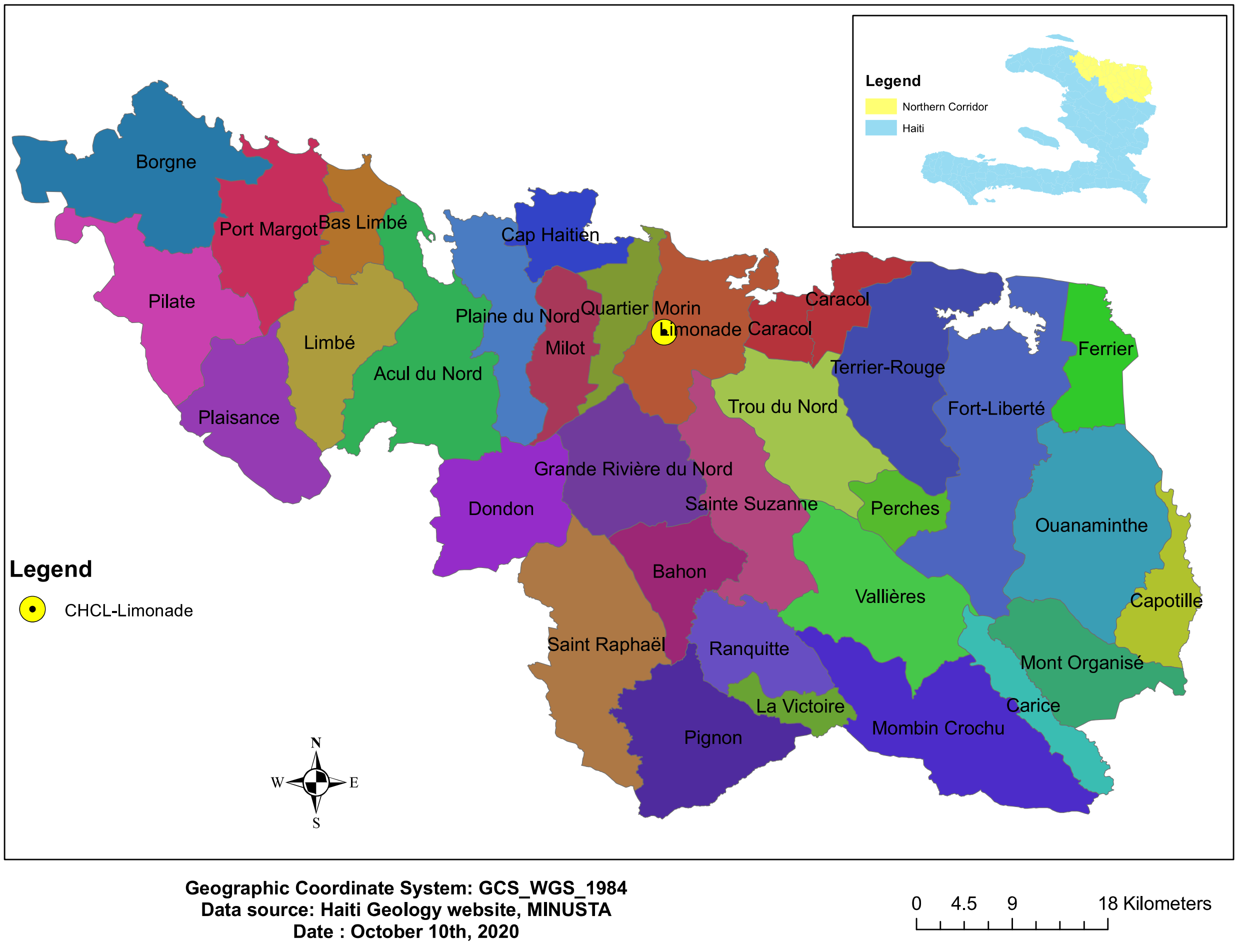
Central laboratory-based water testing services can be complemented with smaller labs, field-based testing and other programs. To institute these programs most effectively, there is a need to identify communities that are vulnerable to cholera outbreaks accounting for both community-level factors that increase waterborne disease risk and access to water testing. Two likely factors contributing to waterborne disease risk that can be investigated using secondary source data are socioeconomic status and the types of water bodies present in a community, as this will influence the sources of water used by households. Additionally, the travel time required to transport water samples to the central laboratory must be considered, accounting not just for distance, but also road conditions and available transportation services. In this case study, we analyze the vulnerability of communities in the Northern Corridor of Haiti to waterborne disease. To assess access to the water testing lab at CHCL, travel time analysis was conducted based on distance, road topography/elevation, road conditions, and transportation type. Additionally, the effect of community-level socioeconomic factors and water sources on cholera infection rate are analyzed. The results will be used to prioritize municipalities for implementing small drinking water testing labs or field-based testing, training, organization, supply, and communication programs necessary to keep both rural and urban water sources reliably safe for Haiti's growing population.

2.2. Method

2.2.1. Study area description

The Northern Corridor of Haiti includes 32 municipalities (Figure 2-1), which are administrative areas representing towns governed by a mayor and providing most governmental services. Some municipalities have long travel times to Limonade due to distance, high elevation, and poor road conditions. The main cities and economic hubs in the Northern Corridor are Cap-Haitian, Fort-Liberty, Ouanaminthe, Limbé, Caracol, Limonade and Trou-du-Nord. The Northern Corridor is bounded by the Dominican Republic to the east, by the departments of Centre and Artibonite to the South, by the Northwest department to the west, and by the Atlantic Ocean to the north.

The population of the Northern Corridor, which includes the North and North-East departments, is about 1.46 million with an average of 45,661 individuals per municipality. The municipality with the smallest population is Caracol (population 7,714) and the municipality with the largest population is Cap-Haitian (population 274,404). The proposed laboratory location of Limonade is a suburb of Cap-Haitian where most residents purchase drinking water from privately-owned kiosks. These vendors have become an increasingly important provider of drinking water to the Haitian population since the 2010 earthquake and subsequent cholera outbreak (Patrick et al., 2017). Kiosk owners are the primary target user of the laboratory, but testing will also be available to municipal governments, NGOs, and other users.



Geographic Coordinate System: GCS_WGS_1984
Data source: Haiti Geology website, MINUSTA
Date : October 10th, 2020

Figure 2-1. Municipalities in the Northern Corridor, Haiti.

The Northern Corridor is characterized by contrasting high mountains and lowlands. The municipality with the highest elevation is Plaisance (877 meters above sea level) and the lowest elevation is in Fort-Liberty at sea level with an average elevation for the municipality of 438 meters. The Northern Corridor has two types of climates, a semi-humid climate in the western part of the region and a semi-arid climate in the eastern part.

2.2.2. Data compilation and variable definition

Variables used in the analysis of travel time and cholera infection risk are summarized in Table 2-1. To assess the gains in accessibility of drinking water testing services that will be achieved throughout the Northern corridor with the establishment of the water testing lab, travel time to take water samples from remote areas to CHCL in Limonade was analyzed. Road conditions, elevation/topography and distance were analyzed as explanatory variables for travel time. Factors with substantial variation in time, such as traffic, road blockages due to political unrest, and weather are incorporated in the error terms in the statistical analysis of travel time. A dataset of travel times in a private car between Cap-Haitian and focal points in the Northern Corridor was gathered from the driver logbooks for two USAID projects based in Cap-Haitian: the USAID-Avanse Project in the Northern Corridor where fourteen drivers were traveling for six years and the USAID-Reforestation project, where seven drivers were traveling for three years. The departure time from the main office in Cap-Haitian to other municipalities in the Northern Corridor was subtracted from the arrival time to municipalities based on the vehicle logbook.

Table 2.1. Data variable descriptions, sourcing, and processing.

Data	Description	Sources	Processing Methods
Municipalities	Boundary of territories administratively governed by a mayor.	Haitian Institute of Statistics and Informatics (IHSI)	Collection of data is done through reports of IHSI.
Elevation/ topography	Topography/elevation of the municipalities above sea level.	Google Earth (Google Inc., Mountain View, CA)	Google Earth used to identify the most populated area of a municipality and its elevation above sea level.
Population	Number of individuals living in each municipality in 2015.	Haitian Institute of Statistics and Informatics (IHSI).	Population recorded from report *Estimation Population Total.* (IHSI, 2015)
Cholera infection rate	Percentage of individuals affected by cholera from 2010 to 2013 in each municipality.	Massachusetts Medical Society, cited (Barzilay et al., 2013).	Collection of data from secondary source.
Number of water bodies	Number of rivers, springs, lakes, lagoons, and coast within the municipality boundaries.	National Centre of Geo-Spatial Information (CNIGS) and IHSI.	Counting rivers, springs, lakes, lagoons crossing, bordering, or contained in the municipalities or sea in the coastal Municipalities.
Distance	Distance to by road from each municipality to Limonade.	Google Earth (Google Inc., Mountain View, CA)	Ruler tool in Google Earth used to measure roads by segment between the municipality and Limonade.
Travel time	Time to travel between each municipality and Cap-Haitian.	Travel logs of USAID-AVANSE drivers.	Time required as recorded in travel log divided by distance traveled.
Road conditions	Based on percentage of paved and unpaved road, maintenance, potholes, and sinkholes.	Observations during fields activities in the Northern Corridor and Google Earth imagery.	
Indicators of monetary poverty and deprivation in living standards	Metrics defining income levels and living standards.	Indicators computed by Inter-American development Bank (IADB) in Haiti, from 2009 to 2020	Indicators obtained from IADB reports.

To estimate travel time to the water testing lab without access to a private car, travel time data through paid transportation were analyzed. Paid transportation is travel using privatelyoperated mass transit services by bus, van, or truck that are common in Haiti. Twenty employees of the USAID-Avanse project recorded travel time data over six years. This dataset of paid travel time between Cap-Haitian and municipalities in the Northern Corridor enabled the computation of average traveling time through paid transportation. The paid traveling time estimates are longer than private transportation traveling time estimates due to drivers needing to stop to collect and drop off passengers along the route.

To identify roads and compute the distance between the main office and the municipalities, Google Earth (Google Inc., Mountain View, CA) was used. Road identification consisted of counting and marking visible roads on the satellite images from Google Earth by using the ruler tool and marking the pathway for each straight segment along the roads. The municipality map layer was downloaded from the United Nations Mission for the Stabilization of Haiti/Mission des Nations Unies pour la Stabilisation d'Haïti (MINUSTHA) database to locate the boundaries of the municipalities (minustah.unmissions.org) and ArcMap version 10.7.1 (ESRI, Redlands, CA) was used to perform geospatial analysis. Populated areas were digitized with a combination of global positioning system (GPS) data (Garmin GPS MAP 76CSx; Garmin International, Inc., Olathe, KS) (Frerichs et al., 2012) and Google Earth satellite images (showing occupied households) to locate populated areas within the municipalities.

2.2.3. Travel time analysis

Road conditions may impact travel time. In rural areas of Haiti, many unpaved roads are in poor condition and characterized by potholes and sinkholes. The rainy season makes many roads impassable with mud, flooding, and damaged bridges (Fix & Loomis, 1998). In most cases in the Northern Corridor, unpaved roads have sinkholes and potholes or are characterized by depressions and sagging. To assess travel time for the route from each municipality to Cap Haitian, three explanatory variables were used: road distance to Cap-Haitian (D), average elevation (E) of the municipality, and road conditions (RC). Road conditions for the route from each municipality to Cap Haitian were assessed from Google Earth Pro Engine imagery and confirmed in the field by engineers working for the Direction Départementale de l'Agriculture Nord (DDAN)/North Departmental Directorate of Agriculture who travel the routes frequently. The percentage of the route that is paved, maintenance, mud, potholes, and sinkholes (Table 2-2) are used to classify the road conditions of each route as good, fair, or poor. The average transportation time (minutes/km) is computed by dividing the average travel time by the road length.

Table 2.2. Road condition classification for routes from municipalities to Cap-Haitian.

Road Condition	Percentage of Road Paved	Description
Roads in Good Condition	80% to 100%	Paved and well maintained.
Roads in Fair Condition	50% to 79%	Poor maintenance over paved and unpaved portions of the road.
Roads in Poor Condition	0% to 49%	Muddy, deep potholes, sinkholes, cracked pavement

Sources: Google Earth Pro Engine imagery and field confirmation

2.2.4. Analysis of community characteristics

To further analyze the vulnerability of municipalities to cholera outbreaks in the Northern Corridor, the relationship between the types of water bodies in a municipality, socioeconomic risk factors, and the cholera infection rate were assessed. These factors were selected because they are assessed at the community level and are available from secondary source data. The percentage of individuals affected by cholera from 2010 to 2013 in each municipality was taken from Barzilay et al. (2013). To count water bodies, data on the locations of rivers, springs, lakes, and lagoons was obtained from the National Center for Geospatial Information/Centre National d'Information Géospatiale (CNIGS) and the Haitian Institute of Statistics and Information/Institut Haitien de

Statistique et d’Informatique (IHSI). We counted the number of rivers, springs, and lakes/lagoons per municipality. We represented coastline as a dummy variable (presence is 1 and absence is 0). The socioeconomic indicator of monetary poverty (IMP) and the indicator of deprivation in living standards (IDLS) (Pokhriyal et al., 2020) estimated by InterAmerican Development Bank (IDB) are relevant integrated metrics to analyze the effects of socioeconomic status on the community-level cholera infection rate in the Northern Corridor. To complete the analysis, the population of the Northern Corridor municipalities published by the IHSI (MEF -IHSI, 2015) were collected to analyze the correlation between the cholera infection rate and population density. We assume linear relationships between the rate of individuals affected by the cholera, the population density, and the distance from the City of Cap-Haitian, which is close to Limonade.

2.2.5. Statistical analysis

First, Pearson’s correlation was calculated between cholera infection rate, number of water bodies, variables from the travel time analysis, and ancillary demographic variables (population and population density). This explored potential relationships between the two sets of analyses and potential confounding factors. To determine the factors affecting travel time, Pearson’s correlation was calculated between recorded travel times in private vehicles and the explanatory factors of distance, elevation, and percentage of the road that is paved. Descriptive statistics (mean, minimum, maximum, range, standard deviation, coefficient of variation) were calculated to compare travel time between road condition classes and between paid and private transportation.

Pearson’s correlation was calculated between cholera infection rate and the number of water bodies of each type (rivers, springs, and lakes-lagoons) with the North and Northeast departments analyzed separately due to substantial differences in prevalent water body types and urbanization. Additionally, an unpaired two-sample *t*-test was performed to determine if cholera rate was significantly different between coastal and inland municipalities. Where significant correlations were found, Poisson regression was used to explore the relationship between the water body type and cholera infection rate. Poisson regression was used because the dependent variable, cholera rate, is a count variable. Statistical analyses were performed using Stata 14.0 (StataCorp, College Station, TX).

2.3. Results

2.3.1. Correlation of variables

There is enough evidence to conclude that there is a significant positive correlation between travel time in a private vehicle and distance traveled, percentage of the road that is paved, and elevation change based on Pearson's correlation coefficient (Table 2.3.). The distance from a municipality to Cap-Haitian is not significantly correlated with road conditions or cholera infection rate (Table 2.3).

Table 2.3. Correlation coefficients, travel time and private transportation.

Dependent variables	Correlation Coefficient
Distance	0.86[1]
Elevation	0.63[1]
Percentage of road paved	0.81[1]

[1] Significant correlation ($p < 0.01$)

That means we cannot conclude that the municipalities farthest from the urban center of Cap-Haitian or with the poorest quality roads have the highest risk of cholera infection. On the other hand, the cholera rate and the population density have a significant positive correlation, so urban populations may be more vulnerable overall (Table 2-4). Thus, making urban water kiosk operators the main target user of the water testing lab is a reasonable strategy. Additionally, the correlation of total water bodies with population density is significant indicating that inhabitants are likely to live in areas with availability of water.

Table 2.4. Pearson's correlation coefficient of analysis variables

Independent variables	Correlation Coefficient	P-value
Distance and cholera rate	0.12	0.52
Population density and cholera rate	0.39[2]	0.03
Distance and population density	-0.23	0.20
Distance and road conditions	0.63[1]	0.00
Water bodies and population density	0.83[1]	0.00
Water bodies and elevation	0.19	0.20

[1]Significant correlation ($p<0.01$), [2]Significant correlation ($p<0.05$)

2.3.2. **Travel time analysis**

The travel time from municipalities to the USAID Office in Cap-Haitian can vary widely (Figure 2-2) and is not strictly determined by distance. Table 2-5 shows descriptive statistics for ten trips to four selected municipalities. From Ouanaminthe to Cap-Haitian, the road is completely paved which provides the lowest average travel time of 1.32 min/km with lowest minimum and lowest maximum. For the remaining municipalities, the roads are both paved and non-paved and the non-paved parts have a large effect on travel time. For instance, Grande Riviere-du-Nord is in the highlands, and drivers recorded the highest average travel time of 3.18 min/km with highest minimum of 2.05 min/km and highest maximum of 4.63 min/km.

Table 2.5. Descriptive statistics of travel time via private transportation.

Municipalities	Road Conditions	Distance (km)	Travel Time (min/km) Recorded					
			Min	Max	Mean	Range	Standard Deviation	Coefficient of Variation
Terrier rouge, CASB	Good	35.7	1.04	2.50	1.48	1.46	0.51	35%
Ville de Ouanaminthe	Good	67.8	1.02	1.75	1.32	0.74	0.25	19%
Dosmond	Good	74.0	0.93	2.19	1.49	1.26	0.33	22%
Grande Rivière-du-Nord	Fair	19.0	2.05	4.63	3.18	2.58	0.68	21%

Even though this municipality is the closest to Cap-Haitian, drivers need as much time as to travel to municipalities twice as far away. Also, the standard deviation for Grande Riviere du Nord is the greatest. The roads to this municipality are mostly unpaved, making it more susceptible to uncertain travel times associated with weather. Further research might explore the effect of weather on travel time. The highest coefficient of variation of Terrier-Rouge may be due to traffic issues because the road is completely paved and is used by many travelers.

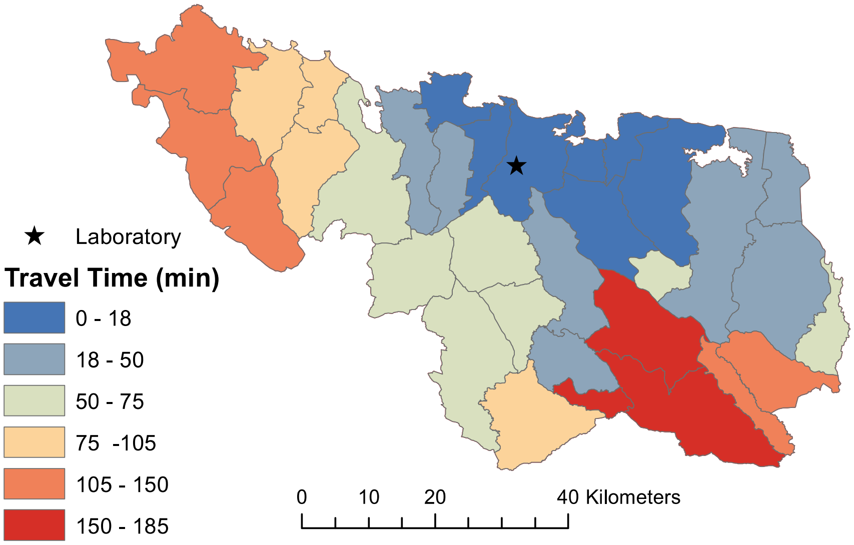


Figure 2-2. Mean travel time in minutes in a private vehicle between each municipality and the water lab.

Travel times for paid transportation are much higher than with a private vehicle. For instance, from Ouanaminthe and Grande Riviere du Nord to Cap-Haitian the average travel time are 4.3 min/km and 5.4 min/km, respectively, as compared to 1.3 and 3.2 min/km with private transportation. Travel time is significantly correlated with distance, elevation, and road conditions. We recorded a wide range of average travel time values for paid transportation based on road condition (Table 2-6). The greatest average travel times were recorded for travel in highlands with poor road conditions; private drivers record and average of 2.18 min/km whereas paid transportation averages 5.28 min/km. Since there is long distance between rural areas and urban centers in Haiti, rural folks must huge transportation cost to get access to cities and necessary chemicals to treat their water. Unfortunately, most of them fall below the low-income threshold which serves as disincentive for them to treat their drinking water.

Table 2.6. Average travel time in private and paid transportation by road condition.

Road Condition[1]	Average Private Transportation (min/km)	Average Paid Transportation (min/km)
Good	1.28	4.38
Fair	1.79	4.89
Poor	2.18	5.28

[1]Road condition classes are described in Table 2

2.3.3. Water body effects

Water bodies are vectors of cholera particularly if they are used for household water supply or recreational activities. There was a significant correlation of cholera infection rate with the number of springs and the presence of coastal in a municipality for both the North department and the whole Northern Corridor. However, no significant correlation was observed for the Northeast department (Table 2-7). There was not a significant difference between coastal and inland municipalities based on an unpaired two-sample *t*-test (*P* = 0.54).

Table 2.7. Correlation coefficient: water bodies vs cholera infection rate.

Spatial Areas	All Water Bodies	Rivers	Springs	Lakes-Lagoons
North	0.47[1]	-0.12	0.47[2]	0.32
Northeast	0.17	0.12	0.14[1]	0.01
Northern Corridor	0.42[1]	-0.02	0.42[1]	0.12

[2]Significant correlation ($p < 0.01$) [1]Significant correlation ($p < 0.05$)

Due to the presence of springs and coastal was significantly correlated with cholera infection rate, a Poisson regression was performed between the two variables (Table 2-8). The number of springs in a municipality explained 48% of the variance in cholera infection rate in the North department. Based on the slope of the regression line, an expected increase in infection rate of 0.52 per 100 people would be expected for each additional spring in a municipality. Due to the significant correlation between number of water bodies and population density and between infection rate and population density (Table 2-4 above), there is a potential confounding effect of population density. Therefore, these results should be interpreted cautiously. However, the presence of a significant effect of springs as opposed to other water bodies suggests the need for more study on the role of springs as a vector for cholera transmission.

The effects of springs may be explained by households collecting untreated drinking water from springs within polluted source areas whereas the coastal effects are due to intensive recreational activities in the North department (Table 2-8). There are no effects of water bodies on the cholera rate in the Northeast department. The economy of the Northeast department is centered in the city of Cap-Haitian leading to frequent travel between the city and remote areas. This may be the dominant vector of cholera spread in this region. Therefore, our analysis demonstrated that the presence of springs and coast are the two water body types that correlate with cholera infection rate as shown through the Poisson regression and *t*-test. This finding supported the result that reveals that cholera outbreaks in Africa and Latin America in 1970 and 1991, respectively, were mainly through coastal communities (Huq et al., 2005). In conclusion, in the Northern Corridor, springs were significantly correlated with cholera rate, but not in the less urbanized North department.

Table 2.8. Poisson regressions: cholera infection rate (y) and number of springs (x) in a municipality

Spatial Area	Springs	Intercept	χ^2
North	0.036[1]	2.07[1]	18.8
Northeast	0.038	2.10[1]	0.6
Northern Corridor	0.034[1]	2.11[1]	18.0

[1] Coefficient significantly different from 0 ($p < 0.01$)

2.3.4. Socioeconomic effects

Some previous research has indicated that households living in poor socioeconomic conditions are more severely impacted by infectious diseases due to poor hygienic conditions (Richterman et al., 2019). However, correlation between cholera infection rate and both the indicator of monetary poverty and the deprivation in living standards indicator, two relevant socioeconomic indicators, were not significantly correlated with cholera infection rate ($P > 0.05$ for all correlations). Therefore, we deduce that communities of all types were affected in the 2010 cholera outbreak.

2.4. Limitations

One limitation of this research is the analysis of water body presence rather than water sources used. However, it is a useful first step in prioritizing municipalities for further analysis. Further research is needed that considers which water sources are used in a community and includes traditional wells, borehole wells, kiosks, and water sold in bottles or plastic bags. The data source of the water body counts (IHSI) is from reliable ground-based surveys. However, it is possible that some smaller springs or streams were missed, which is another limitation.

2.5. Conclusions

The presence of springs in a community is significantly associated with cholera infection based on correlation and regression analysis. Rivers, lakes, lagoons, and coastline are not significantly associated with cholera infection rate. Thus, cholera prevention programs may consider targeting communities where springs are present and emphasize safe use and protection of these water sources. Even though socioeconomic factors play a key role in health outcomes at the individual and household level, our correlation analysis did not find a significant effect of these metrics on cholera infection rate at the community level in the Northern Corridor. While cholera prevention programs should target vulnerable groups within a community, the community-level socioeconomic indicators analyzed in this study do not appear to be useful for assessing cholera infection risk.

Access to the water testing lab in Limonade, near Cap-Haitian, may lead to a more informed public of risk for cholera and other waterborne diseases but only if they are able to transport water samples within the time required for accurate results. Our analysis shows that travel time to a laboratory cannot be predicted from distance alone. Poor road conditions and large elevation change can substantially increase travel time. Additionally, the correlation between population density and distance from Cap-Haitian is low, indicating some municipalities far away from cities have large populations with long travel times to the laboratory. We also found large travel time differences between private and paid transportation, so access to transportation services must be considered. We conclude that municipalities should be prioritized for programs to expand remote testing capabilities based upon the distance, road condition, and elevation change to Limonade, the number of springs, and the population density. However, further assessments are needed to determine municipalities with appropriate infrastructure and willingness of local government to implement drinking water testing and treatment. In the meantime, the Ministry of Public Health and NGOs working in the health sector should make available simple chemicals such as “potable aqua water purification tablets” for households in remote areas to access safe drinking water.

CHAPTER THREE: KIOSK WATER QUALITY ASSESSMENT AND FOR-PROFIT KIOSK OWNERS' WILLINGNESS TO PAY FOR DRINKING WATER TESTING IN NORTHERN OF HAITI

Abstract

To respond to health concerns related to the 2010 cholera outbreak in Haiti, for-profit kiosks have been promoted to sell safe drinking water to household members across the country. Years after the implementation of drinking water kiosks, waterborne diseases are still common in the Northern Corridor of the country. This paper assessed the quality of drinking water sold at for-profit kiosks in the municipalities of Cap-Haitian, Limonade and Quartier Morin and the kiosk owners' willingness to periodically test their water and willingness to pay for testing. Water samples from randomly selected kiosks were tested for total coliforms, *E. coli*, pH and conductivity at a water testing laboratory at the Campus Henry Christophe of Limonade. Additionally, the operators of the kiosks were surveyed and logistic and ordered probit regression were used to determine the main factors that will increase the willingness of kiosk owners to pay for water testing services. In areas of Cap-Haitian with poor sanitation, the for-profit kiosk drinking water quality is poor with presence of *E. coli*, demonstrating the need for improved maintenance and surveillance of kiosks. The education level of clients and potential regulations are two significant factors that increase the willingness of private kiosk owners to regularly test their water. Private kiosk monitoring is a key strategy for public health authorities and drinking water regulators to ensure the safety of the main drinking water source in urban areas of the Northern Corridor.

3.1. **Introduction**

Haiti is among the countries with the lowest rate of access to improved water and sanitation in the Western Hemisphere. This situation was exacerbated by a major earthquake in 2010, which contributed to the rapid spread of a cholera epidemic (Gelting et al., 2013). To meet the emerging need for treated drinking water after the earthquake, private sector water kiosks have been established throughout the country as for-profit small businesses. Though potable piped water would be more sustainable, its inaccessibility to most low-income households makes the distance to gather this safe drinking water at for-profit kiosks less significant (Evans et al., 2013). The for-profit kiosks operate as franchises of provider companies and advertise water treated by reverse osmosis (RO) membrane filtration for sale by one- or five-gallon volumes (Patrick et al., 2017b).

Kiosks are supplemented by other drinking water sources, including bottled water and water sold in single-serving sealed plastic bags. The low quality of piped water after the earthquake caused the number of households in Port-au-Prince using kiosk, bottled, or plastic bag water to increase from 2.1% in 2000 to 49.0% in 2012 (Patrick et al., 2017b). By 2013, a total of 1,340 kiosks were listed in the Port-au-Prince metropolitan area, with the majority (94.3%) reporting that the water was filtered on-site before sale (Patrick et al., 2017c). Most kiosks had only a small cartridge filter for on-site treatment; however, 6.9% of kiosks surveyed had membrane filtration units at the kiosk itself. The exact filter media type and specifications could not be verified, and knowledge of the filter type among respondents was low with more than half of respondents (63.3%) reporting they did not know the type of filter installed. This may lead to some kiosk water being unsafe to drink.

To guarantee safe drinking water to people worldwide, several studies have assessed water quality at kiosk facilities. Analysis of water samples across five villages in Ghana indicated that households using drinking water from for-profit kiosks had lower incidence of *E. coli* in their drinking water than those using untreated surface water (MacDonald et al., 2013). In Haiti, drinking water testing of for-profit kiosks in Port-au-Prince showed that 90.9% of samples met World Health Organization (WHO) microbiological guideline at the point of sale with *E. coli* nondetectable in a 100-mL sample (Patrick et al., 2017b). Of the 9.1% that tested positive for *E. coli*, most of them were in the WHO “low risk” range (1–10 MPN/100 mL). When these kiosks were resurveyed one to two weeks later, 84.1% showed no detectable *E. coli* (Patrick et al., 2017b). These results suggest that the treatment methods used by kiosks water are not fully effective or kiosk owners have not followed treatment protocols.

To maintain consistently safe water supplies, improved monitoring of drinking water treatment facilities such as for-profit kiosks is one of the most promising strategies to improve the safety of drinking water in Haiti, (Cronk et al., 2015). Water supply testing generates data on the safety and adequacy of drinking water supply to contribute to the protection of human health (Howard & Bartram, 2005). For example, periodic microbiological testing may prevent typhoid outbreaks in areas where heavy rains drain microbes and other contaminants to stagnant locations (Wright et al., 2016). Therefore, the Director of the Ministry of Health branch North in Cap-Haitian aims to implement strategies to overcome the water safety issues and increase the visibility of climate-related hazards, such as salinity and heavy rainfall (Personal communication, Charles & Greggio, 2021).

In addition to testing, periodic surveys of water treatment supply inventory at drinking water kiosks is another strategy to ensure proper operation of the drinking water treatment facilities (Rathor et al., 2013). Financial constraints may cause the deterioration of facilities from deferred maintenance and/or delay in the purchase of assets (Craun & Calderon, 2001). Inventory assessments in Korea highlighted that those required gaps could be overcome to ensure the appropriate drinking water services management (Dorea et al., 2020).

For a drinking water testing and facilities inventory program of for-profit kiosks to be successful, the kiosk owners must show willingness to pay for and facilitate both activities. Kiosk owners in Cap-Haitian would be willing to pay to test their water if there is a clear indication that this service is worthy and that it will be possible to generate the funds required to sustain and even expand their water facilities (Whittington et al., 1990a). Willingness to pay for and obtain testing may depend on many factors such as the distance to the laboratory and the water testing fees (Ackermant & Heinzerlinge, 2022).

The establishment of water testing mandates by public health authorities or DINEPA could enhance the kiosk owner willingness to pay for both testing and inventory (Koehler et al., 2015), though this is unlikely in Haiti. Finally, the for-profit kiosk owners' willingness to test their water and participate in inventory surveys may increase if the laboratory provides certificates of participation that can be used in marketing. However, the characteristics of the clients served by the kiosk, such as education level, may influence the marketing advantage of certification. The factors affecting willingness to pay must be validated through quantitative and qualitative metrics to determine the combination of factors that will motivate water testing (Kaminsky & Jordan, 2017).

To provide drinking water testing, a drinking water testing laboratory was established through an effective partnership between the United States Agency for International Development (USAID) and the State University of Haiti branch Campus Henry Christophe of Limonade (CHCL) technically supported by Auburn University (AU). The drinking water testing laboratory aims to monitor drinking water supplies in the Northern Corridor of Haiti to prevent waterborne disease outbreaks in the region. A business plan has been developed and the best marketing strategies were developed to reach different drinking water market segments. This is necessary to increase drinking water testing demand, which is crucial to making the laboratory financially sustainable.

To determine the best strategies to improve drinking water quality and promote drinking water testing in the Northern Corridor of Haiti, this paper analyzes for-profit kiosk drinking water sold to households and the kiosk owners' willingness to pay for and participate in water testing and inventory survey programs. We assessed water quality by testing for *E. coli*, total coliforms, pH, conductivity, and residual chlorine in treated water sold in the Cap-Haitian metropolitan area. The test results are compared to WHO and DINEPA drinking water standards. We also surveyed for-profit kiosk owners to determine how much they would be willing to pay for water testing services and inventory of their water facilities operations. The survey results provided strategic tools to design a kiosk testing and survey program to achieve safe drinking water in the Northern Corridor of Haiti.

3.2. Methods

3.2.1. Study location and sources of drinking water

Cap-Haitian (19°45′33″ N and 72°11′53″ W) is the main coastal city in the North department of Haiti. The city covers an area of 53 km^2 and is at sea level. Due to the absence of treated tap water for households and low quality of natural water from different sources, families purchase plastic bag water, bottled water, and water from for-profit kiosks. The poorest families obtain water from wells and springs followed by traditional treatment, such as tablets. To test drinking water in Cap-Haitian as well as Quartier Morin and Limonade, the two closest municipalities, samples were gathered from for-profit kiosks which are the main drinking water source for low- and middle-income households (Figure 3-1). The populations of these areas are 274,404 inhabitants for Cap-Haitian and its neighborhood of peripheral slums such as Sainte-Philomène, Cité Chauvel, Vertières, and Fort Saint-Michel; 55,145 inhabitants for Limonade, and 27,359 inhabitants for Quartier Morin.

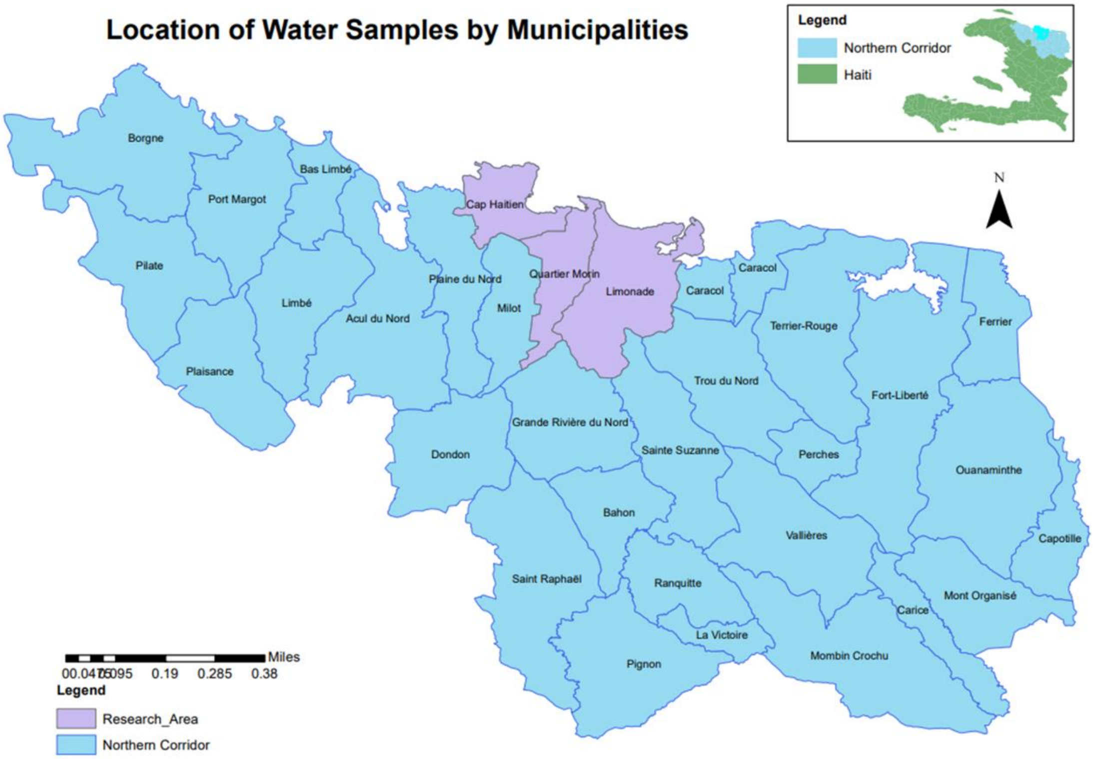


Figure 3-1. Municipalities of the research area.

3.2.2. Kiosk inventory

The kiosk assessment was conducted in the three municipalities of metropolitan Cap-Haitian (Cap-Haitian, Limonade, and Quartier Morin) over a 4-week period in April and May 2022. The goal was to cover all three communes; however, urban areas with higher population density were preferentially chosen when only a portion of a municipality could be covered due to time constraints. The field teams included students from CHCL and a graduate student from Auburn University who were trained on survey procedures.

ArcGIS 10.7.1 (Esri, CA) was used to divide the three municipalities into segments using Open Street Map Road data as boundaries. The enumerators were given maps of each segment and Garmin 62stc Global Positioning System (GPS) units. Private kiosks were defined as vendors located in a commercial building advertising “Treated Water” or “Reverse Osmosis-Treated Water” for sale. Kiosks that were closed at the time of the visit were not recorded with GPS coordinates and a photo was not taken. At each open private kiosk, enumerators explained the purpose of the surveys to the operator and obtained informed consent to conduct a short questionnaire.

3.2.3. Kiosk inventory validation

On completion of the kiosk inventory, at least 10% of the surveyed area was randomly selected and revisited to validate the completeness of the inventory. The selected kiosks were re-inventoried using the same methods to validate the data. To validate a kiosk, it should be operational during the survey and water sample collection. Additionally, enumerators should be able to verify some established equipment to ensure that a real water system is installed (Photo 3-1).

Photo 3.1. Kiosks and kiosk water testing.

3.2.4. Surveys

A complete questionnaire was used to collect kiosk name, date of opening, provider company name, water delivery mechanisms, kiosk equipment, willingness to pay for testing, consumers' satisfaction, possible regulations, raw water sources, and the accessories and their lifetime. The owner's name and contact information, kiosk street address, GPS coordinates, and a photo were also taken at each kiosk. We planned to survey all 93 kiosk owners. Unfortunately, only 36 questionnaires were completed due to the refusal of numerous kiosk owners to provide information. However, the surveys covered all three municipalities, reducing possible selection bias and capturing a range of demographics among kiosk owners.

3.2.5. Water quality testing

At a total of 93 kiosks, at least one water sample was collected on-site using a sterile sampling bag. Samples were stored in cooler boxes with ice and delivered to the CHCL laboratory at most one hour after collection. On arrival at CHCL, samples were tested by lab technicians for pH and conductivity using an electrode sensor (Hanna Instruments; Woonsocket, RI). Residual and total chlorine were measured using a *N, N*-diethyl-*p*-phenylenediamine (DPD) colorimeter (LaMotte Co., Chestertown, MD). Tests for total coliforms and *E. coli* were performed using membrane filtration (EPA method 1604) with Difco MI agar plates (BD Biosciences, Franklin Lakes, NJ) and a 100 mL sample volume. The test result is the total number of coliform bacteria and total number of *E. coli* per 100 mL (Photo 3-2). Kiosks with water samples that tested positive for *E. coli* were resampled as soon as possible within one week to determine if the positive test was a temporary or consistent problem. Kiosk operators were informed of the positive results and reason for the retest. A total of 183 water samples from for-profit kiosks were tested.

Photo 3.2. Membrane filtration operation and incubator for testing for *E. coli* and total coliforms

3.2.6. Water quality analysis

Descriptive and statistical analyses of survey data were conducted using STATA, version 16 (STATA Statistics: An Interactive Hands-On Approach). ANOVA and *t*-tests of equivalence of variance and mean with significance reported at the 0.05 level were used to compare *E. coli* results across municipalities. Downtown Cap-Haitian was compared to its peripheral districts of Bel Air, Sainte Philomène, Cité Chauvel, and Vertières. The *E. coli* analysis was structured according to the health-based WHO guidelines, which state that there should be no E. coli detectable per 100-mL sample, meaning < 1 most probable number (MPN) per 100 mL. Water that does not meet this standard is classified as low health risk (1-10 *E. coli* per 100 mL) or high health risk (11-30 *E. coli* per 100 mL).

3.2.7. Willingness to pay analysis for water testing

Water testing has both public and private benefits. The public benefits include kiosk consumers' reduced risk of contracting waterborne disease outbreaks from water obtained from the kiosk. If consumers are informed of the good quality of water sold, their perception will enhance the valuation of the water which will positively impact kiosk profits (Davis et al., 2001). Therefore, the real water testing value will be the kiosk owners' utility gained from implementing regular water testing. These potential beneficiaries will be surveyed of their willingness to pay (WTP) for water testing service (Grutters et al., 2008). The willingness to pay of kiosk owners will be estimated using stated-preference methods through direct surveys conducted in the field (Breidert et al., 2006).

Logistic regression models were used to analyze the willingness to pay for drinking water testing and the acceptable pricing level considering both quantitative and qualitative factors that could motivate the kiosk owners' choice. However, a first level analysis will be conducted using descriptive statistics. The logit model considers a probabilistic of occurrence events in which both Endogenous and exogenous factors influence the events.

3.2.8. Survey variables

The explanatory variables used to analyze the willingness to pay are the kiosk owner's education level and gender and the water source, number of years of service, and water treatment methods used by the kiosk. Some variables related to the operations and maintenance such as volume of sales, daily consumers, and maintenance cycle have also been gathered. The survey questions asked about current water testing participation, testing motivation, water sample transportation, testing pricing level, water testing mandates, water quality certification, consumer preferences, and, finally, the willingness to pay. Surveys were conducted in April 2022 using printed questionnaires during which enumerators raised questions to kiosk owners about the operation of the kiosks. A total of 36 kiosk owners out of 93 visited fully responded to surveys which was a response rate of 39%. Given the Haitian culture and low awareness regarding relevance of drinking water safety, this 39% of response rate is acceptable to draw substantial conclusions.

3.2.9. Models: Logistic regression

The first model constructed in this study is based on a binomial logistic regression and analyzes the probability of participating in drinking water testing as a dependent variable. Logistic regression tests the probability of a dichotomous event happening, in this case purchasing the service. The predicted proportion of activities follows the logistic model of

$$\frac{\ln(P_i)}{(1 - P_i)} = \beta X_i$$

where P_i is the probability of paying for drinking water testing at a certain price, X is the matrix of exogeneous variables or characteristics of each kiosk owner i, and β is the uniline matrix of coefficients of the regression (Goyanes, 2014). The second model used the multilevel mixed-effects logistic model to determine the acceptable pricing level or maximum amount willing to pay to test drinking water (Whittington et al., 1990b).

3.3. Results

3.3.1. Water tests

Drinking water samples were gathered from 93 for-profit kiosks. Of these, 67% were in downtown Cap-Haitian and peripheral districts such as Bel Air, Sainte Philomène, Champlain, and Vertières, 26% were in Limonade, and the remaining of 8% were in Quartier Morin. Test results showed 47% (49) of private kiosks surveyed were positive for *E. coli*, and 71% (66) were positive for total coliforms. The WHO health risk level measured based on *E. coli* count is given in Figure 3-2.

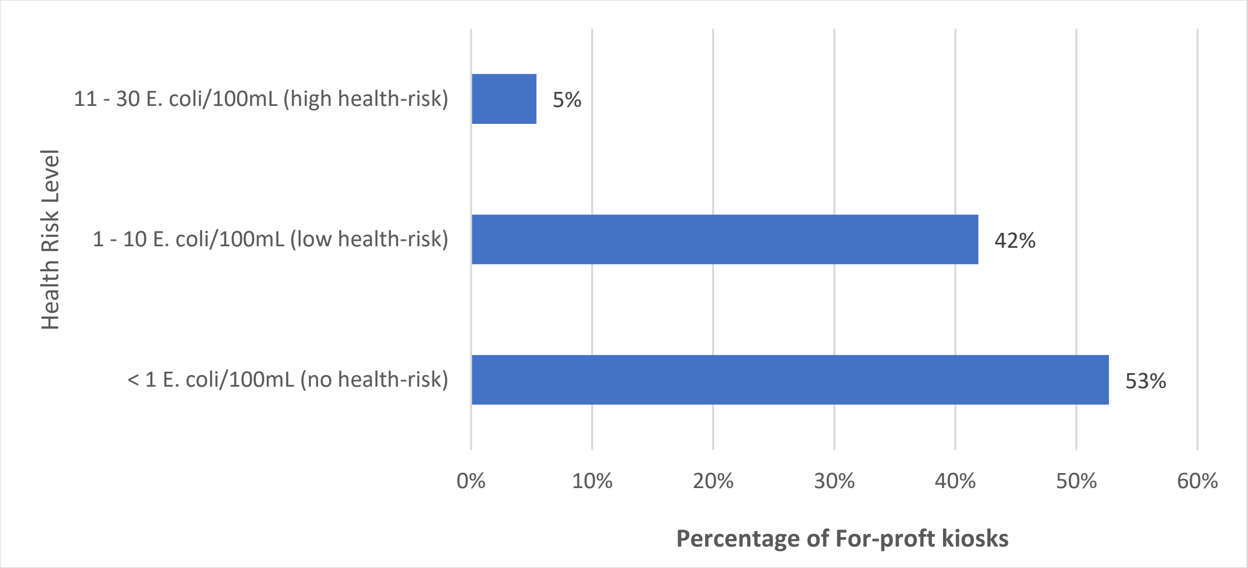


Figure 3-2. Health-Risk Level of Private Kiosks Drinking Water

More than fifty (53%) percent of private kiosks met the WHO guideline value that should be continuously less than one MPN per 100 mL for drinking water. Of the private kiosks testing positive for *E.* coli, most are at the WHO low risk level, whereas 5% showed high risk for human health. Most water coming from kiosks that directly treated the water had no to low health-risk level because the highest *E. coli* concentration detected in water samples is less than 10 MPN/100 mL whereas some distributors or water re-sellers who purchased the treated water from the primary treater showed an *E. coli* rate up to 30 MPN/100 mL (Figure 3-3).

Results are shown for downtown Cap-Haitian and its peripheral districts, where most sanitation concerns are encountered. More than one sample was collected at many for-profit kiosks for validation. The Figures 3-3 to 3-7 show the *E. coli*, total coliforms, residual chlorine levels and pH of drinking water compared to WHO and DINEPA standards. Comparison analysis with the WHO and DINEPA guidelines, the local water regulator, have been made to estimate the health-risk associated with the drinking water coming from each district surrounding Cap-Haitian.

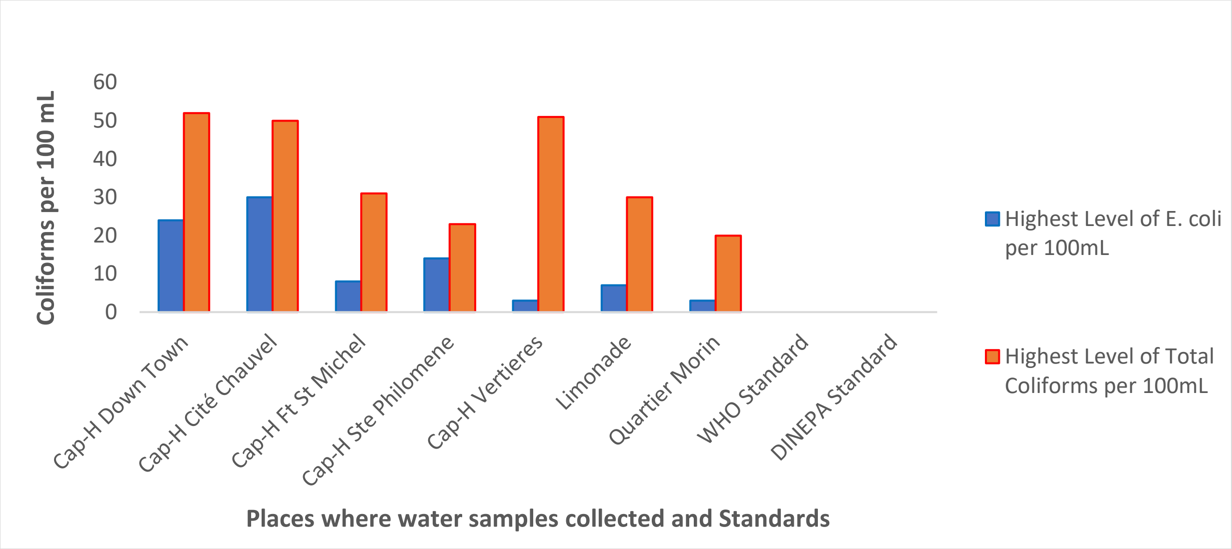


Figure 3-3. Highest observed level of *E. coli* and total coliforms by neighborhood.

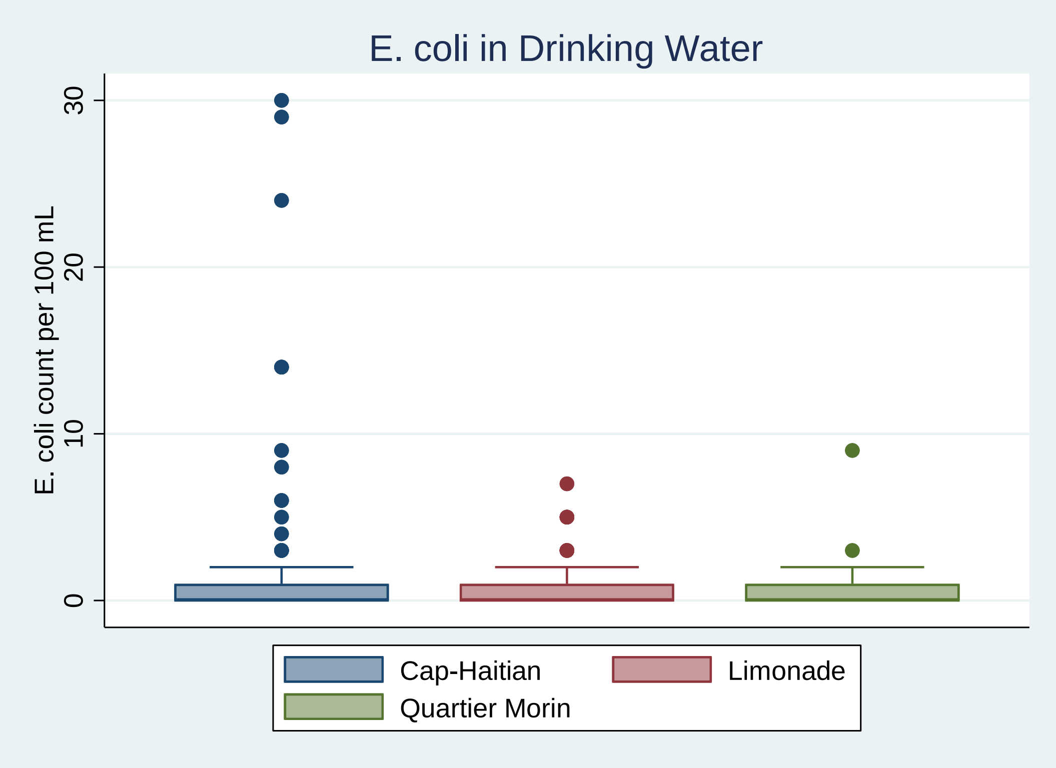


Figure 3-4. Variability of *E. coli* contamination in drinking water samples.

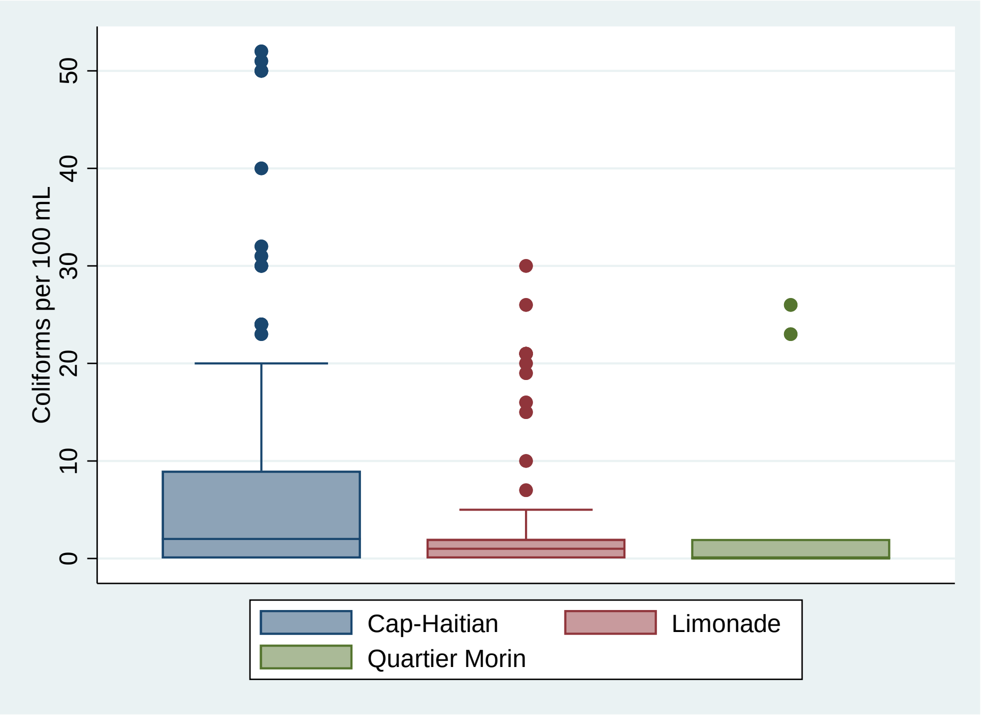


Figure 3-5. Variability of total coliforms in drinking water samples.

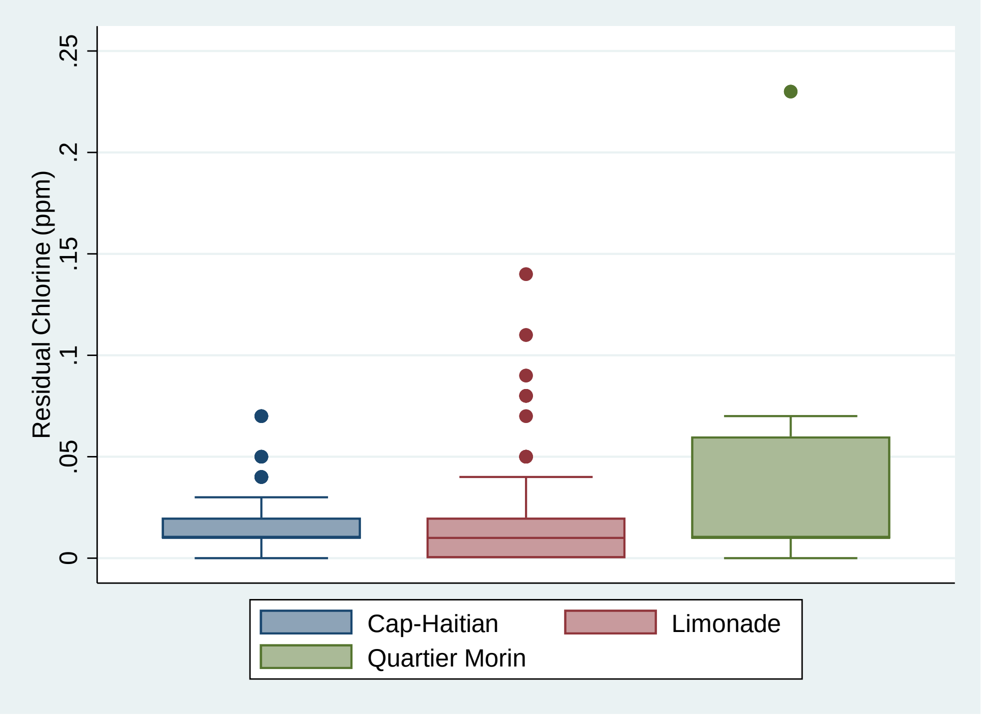


Figure 3-6. Variability of residual chlorine in drinking water samples.

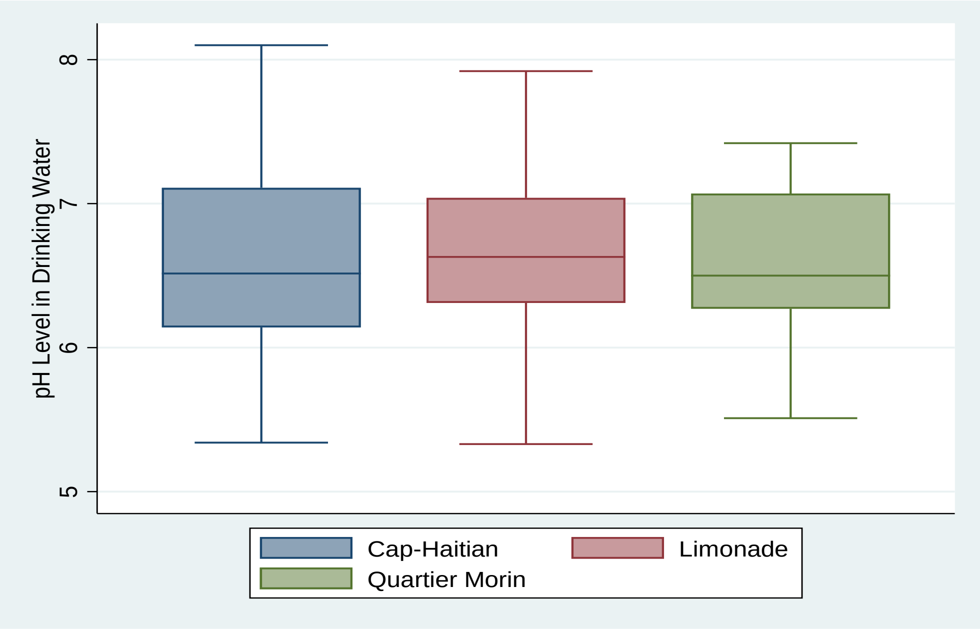


Figure 3-7. Variability of pH in drinking water samples.

Both *E. coli* and total coliforms levels are high compared to WHO and DINEPA standards which are zero coliforms in drinking water. The drinking water sold contains the highest level of *E. coli* in downtown of Cap-Haitian and its peripheral slums such as Cité Chauvel, Vertières, Fort Saint Michel, and Sainte-Philomène. Though other places had lower levels of *E. coli*, the observed levels were still higher than the WHO and DINEPA standards. This may be the result of improper disinfection, demonstrated by the low level of residual chlorine in drinking water sold. The highest measured level was less than 0.3 ppm recorded in Quartier Morin. This means that all samples were below the minimum residual chlorine level of 0.5 ppm recommended by DINEPA and the WHO.

The chlorine level in drinking water sold in municipalities and Cap-Haitian peripheral districts is below the WHO guidelines, which may explain the persistence of *E. coli* in treated drinking water. Cité Chauvel showed the highest rate for both *E. coli* and total coliforms followed by downtown Cap-Haitian where the total coliforms are relatively high in almost all collected water samples. Private kiosks in both municipalities of Quartier Morin and Limonade have better water quality with the highest *E. coli* levels measured at 3 per 100 mL and 7 per 100 mL, respectively. Additional analysis showed that the conductivity of overall drinking water samples tested matched the WHO guidelines, however, in Cité Chauvel, the conductivity is of 1090 very high and that could lead to kidney damage (Lu et al., 2019).

3.3.2. Sample areas and fecal coliforms

The water samples coming from downtown Cap-Haitian and its surrounded districts and slums showed higher level of *E. coli* contamination compared to the water samples coming from Limonade and Quartier Morin. That may be due to the lack of sanitation in Cap-Haitian and surrounding areas and/or the frequent floods recorded in Cap-Haitian. Given the limited space in an urban area, it is common for backyard wells to be located close to a latrine. It was found that some kiosk owners pump raw water from these backyard wells. In addition to sanitation concerns, flooded water may also transport *E. coli* contaminants from spaces that are used for grazing. Table 3.1 summarizes the presence of *E. coli* in kiosk water from locations in the Cap-Haitian municipal area.

Table 3.1. Summary of water test results for locations within the Cap-Haitian metropolitan area.

Water Source Areas	Samples Negative for *E. Coli*		Samples Positive for *E. Coli*		Samples Negative for Total Coliforms		Samples Positive for Total Coliforms	
	No.	%	No.	%	No.	%	No.	%
Cap-H-Downtown	34	63%	20	37%	21	39%	33	61%
Bel'Air	3	75%	1	25%	1	25%	3	75%
Champlain	1	100%	0	0%	0	0%	1	100%
Charrier	1	100%	0	0%	1	100%	0	0%
Cité Chauvel	0	0%	3	100%	0	0%	3	100%
Ft St Michel	4	80%	1	20%	0	0%	5	100%
Haut-du-Cap	1	100%	0	0%	0	0%	1	100%
Ste Philomène	2	33%	4	67%	0	0%	6	100%
Vertières	3	50%	3	50%	1	17%	5	83%
Zo-Vincent	0	0%	1	100%	0	0%	1	100%
Limonade	68	76%	22	24%	41	46%	49	54%
Quartier Morin	8	73%	3	27%	7	64%	4	36%
Total/ Percentage	125	68.3%	58	31.7%	73	39.9%	110	60.1%

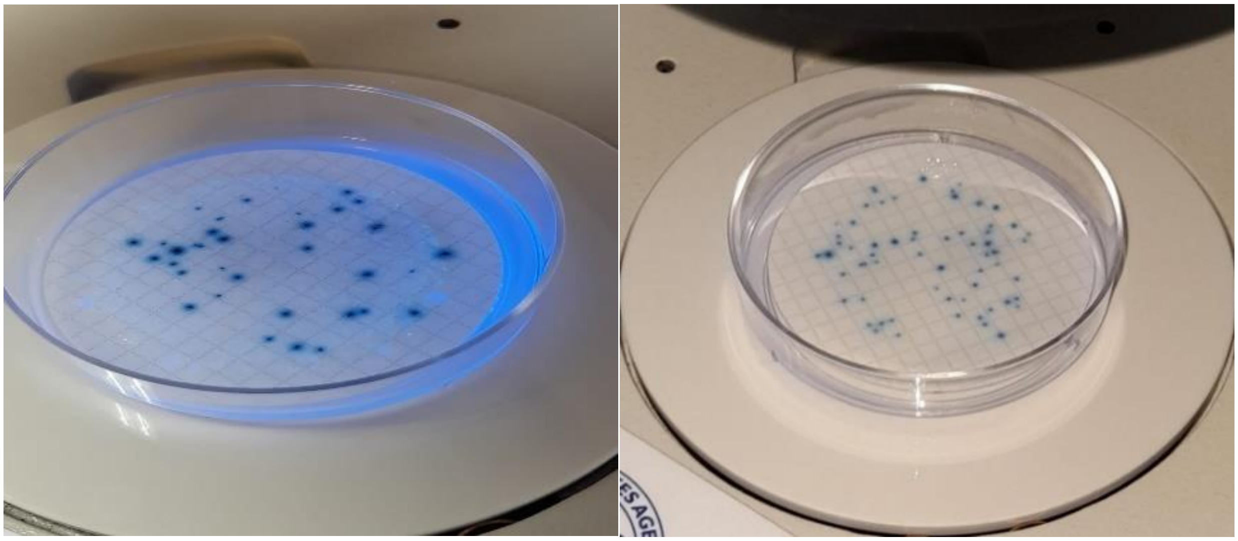


Photo 3.3. Plates with evidence of *E. coli.*

3.3.3. Statistical analyses

Two sample groups were compared to determine whether the *E. coli* contamination level in Cap-Haitian is higher than in other municipalities (Limonade and Quartier Morin).

Table 3.2. *t*-test with equal variances: *E. coli* (count per 100 mL) level in Cap-Haitian vs Limonade-Quartier Morin

Variable	*N*	Mean	Std. Err	Std. Dev.	[95% Conf.	Interval]
Cap-Haitian	82	2.219	0.629	5.696	0.968	3.471
Limonade and Quartier Morin	101	0.515	0.117	1.180	0.282	0.748
				t = 2.933	p-value = 0.0038	

The *t*-test confirmed significant difference between the *E. coli* content (p-value=0.0038) in Cap-Haitian downtown including its peripheral districts and the other municipalities. The highest health risk associated with kiosk drinking water sold in the Northern Corridor is in downtown of Cap-Haitian and the surrounding districts.

Nonparametric analysis using Spearman’s rank correlation did not show a statistically significant relationship between chlorination and the *E. coli* count or pH level (Table 3.3). A residual chlorine level that meets WHO and DINEPA standards is between 0.5 and 2.0 ppm. It is possible that the correlation was not significant because all the residual chlorine values were very low. The pH should be below 8.0. Higher values reduce the efficacy of chlorine for disinfection decreases. Additionally, an acidic pH could limit *E. coli* growth (Blankenhorn et al., 1999), though it also can have corrosive effects on water distribution equipment. However, the lowest pH recorded during the water testing was 5.4, greater than the pH of 4.5 required to kill *E. coli*.

Table 3.3. Spearman's rank correlation of water testing parameters

Tests Parameters	pH	Residual Chlorine
E. coli	0.081 p-value = 0.1819	0.007 p-value = 0.9255
Residual chlorine	-0.099 p-value = 0.2780	-

3.3.4. Vendors' willingness to pay for water testing

i. Descriptive analysis

The for-profit kiosk owners' willingness to pay (WTP) for water testing is fundamentally attributed to their willingness to accept (WTA) compensation for the laboratory conditions, regulators, and consumers' requirements in terms of water quality. Additionally, kiosk owners' awareness of the consequences of waterborne disease outbreak could increase willingness to test their water.

Out of 93 kiosks recorded in the three municipalities, 36 kiosk owners completed the survey, which include 11 (30.6%) women and 25 (69.4%) men (Table 3.4). First, we analyzed the kiosk owners' willingness to pay for water testing based on demographics such as education level and sex. For any age group, kiosk owners are willing to pay for water testing however, women owners would like to pay less than 2,000 gourdes. Male owners within the ages range of 20- to 40-years-old (38.9%) showed the greatest willingness to pay. A key point is that 38.9% of kiosk owners surveyed would not test their water at any price level.

Table 3.4. Kiosk owners' characteristics and willingness to pay for water testing.

Kiosk Owners' Characteristic	Willingness to Pay (Gourdes)					
	2000	2,500	3000	3500	No interest	Total
Female	16.7% (6)	2.8% (1)	0.0% (0)	2.8% (1)	8.3% (3)	30.6% (11)
Age 20-40	11.1%	0.0%	0.0%	0.0%	0.0%	11.1%
Primary school	2.8%	0.0%	0.0%	0.0%	0.0%	2.8%
Secondary school	5.6%	0.0%	0.0%	0.0%	0.0%	5.6%
University	2.8%	0.0%	0.0%	0.0%	0.0%	2.8%
Age 40-60	5.6%	2.8%	0.0%	2.8%	8.3%	19.4%
Secondary school	2.8%	2.8%	0.0%	2.8%	5.6%	13.9%
University	2.8%	0.0%	0.0%	0.0%	2.8%	5.6%
Male	19.4% (7)	13.9% (5)	5.6% (2)	0.0% (0)	30.6% (11)	69.4% (25)
Age 20-40	11.1%	11.1%	2.8%	0.0%	8.3%	33.3%
Secondary school	8.3%	2.8%	0.0%	0.0%	8.3%	19.4%
University	2.8%	8.3%	2.8%	0.0%	0.0%	13.9%
Age 40-60	8.3%	2.8%	2.8%	0.0%	8.3%	33.3%
Secondary school	8.3%	0.0%	2.8%	0.0%	8.3%	19.4%
University	0.0%	2.8%	0.0%	0.0%	11.1%	13.9%
Age 60-80	0.0%	0.0%	0.0%	0.0%	2.8%	2.8%
Primary school	0.0%	0.0%	0.0%	0.0%	2.8%	2.8%
Total	36.1% (13)	16.7% (6)	5.6% (2)	2.8% (1)	38.9% (14)	100.0% (36)

Drinking water kiosks started replacing tap water more than ten years ago in Northern Haiti and gradually increased in prevalence, as demonstrated by the time in operation of the kiosks surveyed (Table 3.5). Of the kiosks surveyed, 19.4% have been in operation for more than 10 years. The remaining 81.6% of kiosks have been established in the last 10 years, which increased the access to safe drinking water as the quality of tap water declined. Most of the drinking water facilities were established five to ten years ago (41.7%). Among the kiosk owners surveyed, 69.4% sourced their water from wells whereas 30.6% purchased their drinking water from water plants that sell treated water to retailers. The treated water is purchased from the water plants on a daily (13.9%), weekly (11.1%), biweekly (2.8%), or monthly (2.8%) basis. Seemingly, all kiosk owners

(69.4%) who source raw water from wells own their private wells, therefore they have pumped the water on-site with inconsistent frequency.

Reverse osmosis systems have required maintenance that should be performed on a regular schedule. Kiosks that have been operating between five and ten years supply most consumers with 16.7% supplying more than 100 daily customers and 19.4% supplying less than 50 daily consumers (Table 3-6). Additionally, 13.9% of kiosks in operation between one year and five years supply 50 to 100 daily customers and 16.7% of these kiosks supply less than 50 customers.

Table 3.5. Water provenance, time in service, supply, and treatment methods.

Water Treatment Methods		Purchased from water Plant	Wells	Total
Duration of operation (years)	Less than 1	2.8%	2.8%	5.6%
	Between 1 and 5	11.1%	22.2%	33.3%
	Between 5 and 10	16.7%	25.0%	41.7%
	More than 10	0.0%	19.4%	19.4%
	Total	30.6% (11)	69.4% (25)	100.0% (36)
Frequency of delivery	Daily basis	13.9%	0.0%	13.9%
	Weekly	11.1%	0.0%	11.1%
	Bi-weekly	2.8%	0.0%	2.8%
	Monthly	2.8%	0.0%	2.8%
	Sourced on-site	0.0%	69.4%	69.4%
	Total	30.6% (11)	69.4% (25)	100.0% (36)
Water treatment methods	Used filter for water received	25.0%	0.0%	25.0%
	Reverse osmosis/chlorine	0.0%	55.6%	55.6%
	Reverse osmosis, chlorine, and UV	0.0%	5.6%	5.6%
	Refused to answer	5.6%	8.3%	13.9%
	Grand Total	30.6% (11)	69.4% (25)	100.0%

The drinking water sold to consumers in the municipalities is treated using many methods. On average 25% of the retailers used filters on-site to treat the water from water plants where 5.6%

provided no answer regarding additional treatment on site. For the kiosk owners who source their water from wells, 55.6% perform treatment with methods including membranes and filters, reverse osmosis, and chlorination for final disinfection; and 5.6% of kiosk owners used reverse osmosis followed by chlorine and UV for disinfection as a treatment method. A total of 13.9% of responders refused to provide details about the water treatment methods. The refusal of some kiosk owners to provide water treatment methods creates uncertainty about the safety of their drinking water.

The drinking water sold by the kiosks is described in Table 3.6. About 81% sold less than 250 gallons per day. The kiosks that have operated for more than five years dominate the market with 61.1% of water sold, however, most (47.2%) sold less than 250 gallons per day. Only newer kiosks sold less than 250 gallons per day and only older kiosk sold more than 250 gallons per day. For reverse osmosis maintenance, 50% of the kiosk owners have done maintenance semi-annually (25%), annually (16.7%), or biannually (8.3%). The remaining 50% of operators do not maintain the kiosk as required for reverse osmosis system. The maintenance of these kiosks consists of filter changing which should be once every three to six months.

Table 3.6. Daily consumers, water sold, and maintenance by kiosks.

Operation and Maintenance	Consumers and Operations	Less than One Year	One to Five Years	Five to Ten Years	More than Ten Years	Total
Daily Consumers	Less than 50	2.8%	16.7%	19.4%	5.6%	44.4% (16)
	50-100	2.8%	13.9%	5.6%	2.8%	25.0% (9)
	More than 100	0.0%	2.8%	16.7%	11.1%	30.6% (11)
	Total	5.6%	33.3%	41.7%	19.4%	100.0% (36)
Daily Gallons Sold	Less than 250	5.6%	27.8%	36.1%	11.1%	80.6% (29)
	More than 250	0.0%	5.6%	5.6%	8.3%	19.4% (7)
	Total	5.6%	33.3%	41.7%	19.4%	100.0% (36)
Osmosis System Maintenance Frequency	Semi-annual	0.0%	5.6%	5.6%	13.9%	25.0% (9)
	Annually	0.0%	8.3%	8.3%	0.0%	16.7% (6)
	Biannually	0.0%	2.8%	5.6%	0.0%	8.3% (3)
	Not Applicable	5.6%	16.7%	22.2%	5.6%	50.0% (18)
	Total	5.6%	33.3%	41.7%	19.4%	100.0% (36)

ii. Statistical analyses

The t-tests (Table 3.7) did not show significant differences in the *E. coli* level in water from kiosks with wells as the primary source and those that have water delivered.

Table 3.7. *t*-tests on *E. coli* level differences between kiosks with different characteristics.

Water Treatment Method

Variable	*N*	Mean	Std. Err	Std. Dev.	[95% Conf. Interval]	
Reverse Osmosis	9	2.889	1.576	4.728	-0.746	6.524
Other	17	3.235	1.384	5.707	0.301	6.169
				t = 0.1566	p-value = 0.878	

Water Source

Variable	*N*	Mean	Std. Err	Std. Dev.	[95% Conf. Interval]	
Well	7	3.428	1.998	5.287	-1.461	8.318
Delivery	19	3.00	1.247	5.436	0.379	5.620
				t = 0.1795	p-value = 0.859	

There was also not a significant difference found in the *E. coli* level between kiosks that did or did not use reverse osmosis system as a water treatment method. Additional research is needed to determine factors affecting kiosk water quality.

Spearman's rank correlation between the *E. coli* level measured in the sample from a kiosk and the owner's willingness to pay for the water testing was not significant (ρ =0.20, P = 0.33). This implies that the kiosk owners dispensing water with the highest health risk are not more or less willing to disburse a significant amount to test the water. It is unclear if the kiosk owners are unaware of the contamination level of their water or if they are careless about their clients' health. We assume that kiosk owners aim to maximize their profits, regardless of the health consequences of the water sold.

iii. Willingness to pay and test water

For current drinking water testing, 38.9% of kiosk owners have never had their water tested whereas 61.1% tested it either in the Dominican Republic (5.6%) or locally using TDS-powder (44.4%), or a test kit (11.1%). Table 3.8 shows that even though some kiosk owners said they never completed water testing, some factors could be good incentives to encourage them to periodically perform testing such as some incentives from the laboratory management (2.8%), the preferences of consumers (33.3%), and regulations by DINEPA (33.3%). On average 11.1% (4) of kiosk owners did not find any reason as an effective incentive to complete water testing.

When asked about sample pick up by laboratory drivers, 22.2% of kiosk owners who had no primary interest in testing would be willing to use this service (Table 3.8). On average 19.4% of kiosk owners are willing to pay up to 750 gourdes for sample pick up whereas 58.3% would pay any price set by the lab. Therefore, providing sample transportation to clients will be crucial to enhance the kiosk owners' willingness to test their water. Finally, based on transportation availability, the testing frequency varies for kiosk owners. On average 2.5% would test their water semi-annually, 38.9% opt for monthly testing, 13.9% would prefer biweekly testing, 11.1% will test their water weekly, and 30.6% will not test or have no frequency preference (19.5%).

Table 3.8. Factors affecting kiosk owners' willingness to test water.

Factors	Options	Kiosk Owner Responses		
		No	Yes	Total
Current Water Testing Method	No Testing	38.9%	0.0%	38.9% (14)
	Dominican Republic	0.0%	5.6%	5.6% (1)
	TDS and Powder	0.0%	44.4%	44.4% (16)
	Test Kit	0.0%	11.1%	11.1% (4)
	Total	38.9%	61.1%	100.0% (36)
Motivation to Test the Water	Depends on the Water Lab	2.8%	2.8%	5.6% (2)
	Preference of Clients	33.3%	2.8%	36.1% (13)
	Ensure Good Water Quality	0.0%	2.8%	2.8% (1)
	Regulations from DINEPA	33.3%	11.1%	44.4% (16)
	None	11.1%	0.0%	11.1% (4)
	Total	80.6%	19.4%	100.0% (36)
Willingness to Pay for Transport Provided	250 – 500 gourdes	2.8%	8.3%	11.1% (4)
	500 – 750 gourdes	0.0%	8.3%	8.3% (3)
	Any Price	19.4%	38.9%	58.3% (21)
	No Willingness to Pay	19.4%	2.8%	22.2% (8)
	Total	41.7%	58.3%	100.0% (36)
Preferred Testing Frequency	Semi-annually	2.8%	2.8%	5.6% (2)
	Monthly	11.1%	27.8%	38.9% (14)
	Biweekly	8.3%	5.6%	13.9% (5)
	Weekly	8.3%	2.8%	11.1% (4)
	No Preference	5.6%	13.9%	19.5% (7)
	None	5.6%	5.5%	11.1% (4)
	Total	41.7%	58.3%	100.0% (36)

iv. Willingness to pay (WTP) cycle

The kiosk owners' willingness to pay varies with the potential frequency of water testing and, it was demonstrated that 36.1% of kiosk owners would prefer to test their water monthly (Table 3.9). About 60.1% of kiosk owners were willing to pay for water testing. The maximum water testing fees should not be greater than 3,500 gourdes because none of the entrepreneurs interviewed will pay greater than that amount to test their water. Even though some kiosk owners showed no willingness to pay to test their water, some incentives could make a significant difference.

Table 3.9. Willingness to pay (amount in gourdes) versus testing frequency.

Frequency	<=2000	<= 2500	<= 3000	<= 3500	Never	Total
Biannually	5.6%	0.0%	0.0%	0.0%	2.8%	8.3% (3)
Once a month	16.7%	13.9%	2.8%	0.0%	2.8%	36.1% (13)
Every two weeks	8.3%	2.8%	2.8%	0.0%	0.0%	13.9% (5)
Weekly	2.8%	0.0%	0.0%	0.0%	8.3%	11.1% (4)
No preference	2.8%	0.0%	0.0%	2.8%	25.0%	30.6% (11)
Total	36.1% (13)	16.7% (6)	5.6% (2)	2.8% (2)	38.9% (14)	100.0% (36)

Table 3.10 describes kiosk owners' concerns about the drinking water laboratory location. Placed on campus in Limonade, 19.4% of kiosk owners found that taking samples to this location will be difficult, and 8.2% of these kiosk owners would test their water monthly. On average 55.6% were not sure whether the location of the laboratory will affect their testing choice of which 22.2% would test monthly if appropriate conditions are provided. An average of 30.6% of kiosk owners have no desired frequency. A kiosk owner who previously tested water in the Dominican Republic found the laboratory location convenient.

Table 3.10. Preferred testing frequency versus the kiosk owners' opinion of the lab location.

Opinion of Limonade	Semi-annually	Monthly	Biweekly	Weekly	None	Total
Difficult to access	0.0%	8.3%	5.6%	2.8%	2.8%	19.4% (7)
Convenient	0.0%	2.8%	0.0%	0.0%	0.0%	2.8% (1)
No influence	2.8%	5.6%	0.0%	8.3%	2.8%	19.4% (7)
No idea for now	2.8%	22.2%	8.3%	0.0%	22.2%	55.6% (20)
Too far away	0.0%	0.0%	0.0%	0.0%	2.8%	2.8% (1)
Total	5.6% (2)	38.9% (14)	13.9% (5)	11.1% (4)	30.6% (11)	100.0% (36)

v. Consumers' requirements and willingness to pay

Table 3.11 describes some expectations that might influence water testing. On average, 66.7% of kiosk owners expected that their sales would increase if consumers were aware of the good quality of their water. On average 63.9% of kiosk owners believed that receiving a certification of good water quality will increase the number of consumers whereas 75% believe consumers will consent to any fees increase. The strongest motivating factor (83.3%) is that kiosk owners would be willing to pay for certification if it is mandatory. Some kiosk owners confirmed that the laboratory manager should pressure the mayor, DINEPA and other agencies to make the certificate a requirement.

Table 3.11. Effect of kiosk owners' expectations on willingness to test water.

Kiosk Owners' Expectations	Maybe	No	Yes	(N)
Water testing will increase clients	16.7%	16.7%	66.7%	(36)
Water certification will increase sale	22.2%	13.9%	63.9%	(36)
Consumer willingness to pay increased fees	22.2%	2.8%	75.0%	(36)
Mandatory certification	8.3%	8.3%	83.3%	(36)

3.3.5. Regression analysis

i. Logistic regression

First, we consider the willingness to pay or willingness to test water as a binary variable to assess the relevant factors that could be incentives for kiosk owners to test their water. Based on previous assumptions, we assumed that daily gallons sold (DGS), the consumers' requirements (CR), testing mandates (TD) by public health agencies and water supply regulators, the willingness to adopt transportation (WAT), and the kiosk owners' education level as the most relevant factions to encourage water testing (Table 3.12).

The results in Table 3.13 demonstrate that none of these variables had significant effects on willingness to pay. However, the testing mandate and transportation services variables, even though they are not significant at the 0.05 significance level, had large positive coefficients and relatively low *P* values, indicating that they may affect water testing choice. The analysis was extended using the multilevel mixed-effects logistic regression through which we categorized the willingness to pay in considering the maximum amount each kiosk owner is willing to pay and we assessed the relevant factors that could affect this.

Table 3.12. Variables and measurement level for regression analysis

Variables	Definition: Questions from the surveys	Measurement
Willingness to test	Consider a scenario in which you were able to test your water for chlorine, *E. coli* and total coliforms. Will you test your water?	Binary
Maximum amount willing to pay	What would be the maximum acceptable price?	Ordinary
Number of gallons sold per day	How many 5-gallon units do you sell each day?	Numerical
Requirements from consumers	Will consumers’ requirements motivate you to test your water?	Binary
Perception that consumers will pay high price	Will consumers who are aware of your water is good quality will accept to pay more?	Binary
Testing mandatory	Will a testing mandate motivate you to test your water?	Binary
Availability of transportation service	Will transportation availability motivate you to test your water?	Binary
Kiosk owners’ education level	What is your “Education level”: 1. None or primary. 2. Secondary or University	Binary
Currently testing water	Do you currently test your water?	Binary
Survey on consumers’ satisfaction	Do you conduct surveys about consumers’ satisfaction?	Binary

Table 3.13. Logistic regression

Willingness to Test	Odds Ratio	Std. Err.	Z	P>Z	[95% Conf.	Interval]
Water Source-Wells	-2.03e-07	0.0005	-0.01	0.995	0	.
Water Source-Purchased	-1.11e-07	0.0003	-0.01	0.995	0	.
Perception that consumers will pay high price	-0.355	0.359	-1.02	0.306	-0.049	2.584
Daily gallons sold	-0.999	0.0014	-0.14	0.889	-0.997	1.002
Currently testing water	1.764	2.582	0.39	0.698	-0.100	31.072
Kiosk owners’ education level	1.159	0.899	0.19	0.849	-0.253	5.299
Availability of transport service	8.074	10.362	1.63	0.104	-0.653	99.876
Testing mandate	14.857	29.271	1.37	0.171	-0.313	706.137
Requirements from consumers	1.789	3.329	0.31	0.755	-0.046	68.695
Surveys on consumers’ satisfaction	4.238	5.557	1.10	0.271	-0.324	55.354
Logistic regression	Number of obs			=	34	
	LR chi2(10)			=	13.61	
	Prob > chi2			=	0.196	
Log likelihood = -12.8448	Pseudo R^2			=	0.346	

Table 3.13 above shows the effects of different variables on the water vendors’ willingness to pay for the water testing services with Odds ratio. Indeed, water sources such as Wells (Odds ratio equal -2.03e-07) water sources such as Purchased treated (-1.11e-07) and have no relevance effects on the vendors’ willingness to pay for water testing services. Additionally, the perception that consumers will pay high price (Odds ratio equals -0.355 and p-value =0.306) and the daily gallons sold (Odds ratio = -0.999 and p-value=0.889) got negative coefficients which means that

these two variables will negatively affect the willingness to pay. This is contrary to expectations. Whereas the "currently water testing at kiosk level got 1.764, (p-value=0.698) which should be negative because when water vendors tested there will be no needs to send it to the laboratory. Even though the following variables do not significantly explain the water vendors' willingness to pay for water testing, Kiosk owners' education level (Odds ratio =1.159 and p-value=0.849), availability of transport service (Odds ratio = 8.074 and p-value =0.104), water testing mandate (Odds ratio =14.857 and p-value = 0.171), and requirements from consumers (Odds ratio =1.789 and p-value=0.755), they would have positive effects on the water vendors. There are two key variables that may be retained as good water testing incentives. For transportation service provided, there are 8 water-vendors who would likely test their water against one who would not likely test it. For the water testing mandatory, there are almost 15 water vendors who would likely test their water against one who would not likely test their water. Even though there is no significant variable, for water testing mandatory and availability of transportation service the odds of water vendors to likely pay for water testing services are 15 and 8 respectively. Further analysis will be conducted using multilevel mixed effects ordered logistic regression to deeply assess the independent variables effects.

ii. Multilevel mixed effects ordered logistic regression

We used the survey data in an ordered logistic regression to estimate the kiosk owners' willingness to pay for drinking water testing in the Northern Corridor of Haiti. The categories were defined as the highest amount that kiosk owners would be willing to pay to test their treated water for microbiological contaminants and chlorine as set up in Table 3.14. The sample size was reduced to 34 because two kiosk owners did not provide consistent data for the explanatory variables used in the regression.

Table 3.14. Maximum amount kiosk owners are willing to pay for testing.

Willingness to Pay	Modalities	Max (gourdes)	Frequency	Percent	Cumulative
Level	0	0	9	26.47	26.47
	1	2000	16	47.06	73.53
	2	2500	6	17.65	91.18
	3	3000	2	5.88	97.06
	4	3500	1	2.94	100.00
Total			34	100.00	

The following analysis was conducted using a multilevel mixed effects ordered logistic regression model to assess the kiosk owners' willingness to pay a maximum amount as set up in the table above. Table 3.15 provides the results of the ordered logistic regression based on survey data using ordered probit model regression. Contrary to the logistic model, which indicated no significant factors explaining willingness to pay, the multilevel mixed effects ordered logistic regression indicated at least one significant factor which is a testing mandate. Kiosk owners' willingness to pay is significantly related to drinking water testing mandates. Thus, if the Ministry of Public Health mandates the water testing followed by enforcement, more kiosk owners will test their water.

The consumers' requirements, transportation availability, daily gallons sold, current water testing practices, raw water source, the perception of consumers' willingness to pay additional fees and the kiosk owners' education level were not significant variables to explain the kiosk owners' willingness to pay. However, the kiosk owners' education level had a positive coefficient greater than one and a relatively low *P* value, so it could increase willingness to pay. For kiosk vendors with secondary and higher education some outreach may increase the willingness to pay.

Table 3.15. Multilevel mixed-effects ordered logistic regression.

Maximum Amount Willing to Pay	Coef.	Std. Err. Z P>Z	[95% Conf.	Interval]
Daily gallons sold	-0.0008	0.001 -0.73 0.463	-0.003	0.001
Currently testing water	0.068	1.016 0.07 0.947	-1.924	2.059
Requirements from consumers	-0.028	1.409 -0.02 0.984	-2.791	2.734
Testing mandatory	4.371	1.678 2.61 0.009	1.082	7.660
Availability of transport service	0.396	0.798 0.50 0.620	-1.168	1.960
Kiosk owners' education level	1.923	1.268 1.52 0.129	-0.562	4.409
Surveys on consumers' satisfaction	0.704	0.951 0.74 0.459	-1.161	2.568
Water source-wells	1.978	1.545 1.28 0.200	-1.050	5.006
Water source-purchased	1.712	1.905 0.90 0.369	-2.021	5.445
Perception that consumers will pay more to purchase DW	-0.837	0.591 -1.42 0.156	-1.996	0.321
Ordered logistic regression		Number of obs =34	15.16	0.1264
Log likelihood = -32.328		Wald chi2(10) with Prob > chi2		
Log likelihood = -32.328		Wald chi2(10) with Prob > chi2		

By utilizing the multilevel mixed effects ordered logistic regression, the results are different. However, only water testing being mandatory (Coeff. = 4.371 and p-value=0.009) significantly explains the water vendors' willingness to pay for water testing services. All other variables used in the model have showed no effects on the water vendors' willingness to pay for the water testing services. However, the kiosk owners' education level shows a positive coefficient almost two indicates, even though the p-value is greater than 0.05, that some outreach may motivate educated water vendors to test their water.

3.4. Conclusion

The drinking water sold at private kiosks in downtown Cap-Haitian and its peripheral districts has poor quality should not be considered as safe drinking water. This poor drinking water quality results from insufficient water treatment methods and irregular facility maintenance. The unsafe drinking water is in some cases in the WHO high-risk level, which increases vulnerability to typhoid and other waterborne diseases. For-profit kiosks in Quartier Morin and Limonade have supplied drinking water with lower health-risk which could be the result of fewer sanitation concerns in these municipalities.

Fortunately, there is some willingness to periodically pay for drinking water testing in Cap-Haitian, Quartier Morin, and Limonade municipalities. This is in accordance with descriptive analysis showing 55% of kiosk owners have been using TDS powder (total dissolved solid powder) to test drinking water at the kiosk level. Testing by the CHCL laboratory could help to prevent waterborne disease outbreaks. However, kiosk owners must be willing to pay for and participate in water testing for this to be successful.

The variable with the largest effect on willingness to pay, based on the ordered logistic regression, is whether testing is mandatory. Even kiosk owners with secondary education and high education (university level) are not significantly inclined to test the treated drinking water sold at their kiosks. Finally, kiosk certification could be a strategic policy to encourage entrepreneurs to test their water and certify the kiosks. Based on these conclusions some incentives would be key to encourage kiosk owners to take water samples to the laboratory besides a testing mandate with enforcement by the Ministry of Public Health.

3.5. Implications

This research reveals health risk concerns related to drinking water for inhabitants in the Northern Corridor of Haiti. The results provide a good understanding of the contaminant levels and suggest additional research that must be performed to support safe drinking water supplies. Further, this research expresses the needs to establish regulations and enforcement for better kiosk water management.

The drinking water testing conducted for the three municipalities of Cap-Haitian, Quartier Morin, and Limonade demonstrated that raw water from areas with low sanitation requires additional treatment efforts to produce safe drinking water. For instance, kiosks in Cap-Haitian with its surrounding slums has a high health-risk whereas kiosk water from Limonade and Quartier Morin, with good sanitation, have safer drinking water supplies. That corroborates the awareness that poor sanitation and hygiene conditions and other environmental effects could be considered as the major causes of source water contamination. Therefore, kiosk water established in poor sanitation areas should provide additional efforts to treat the water before it is sold as drinkable or potable water.

3.5.1 Future research

Given that 63% and 33% of water samples coming from downtown Cap-Haitian and Sainte-Philomène, respectively, tested negative for *E. coli*, it is possible to supply safe drinking water with proper treatment regardless of the sanitation level. Further research must assess the technical water treatment methods used by each kiosk and develop best practices. These best operational and maintenance practices may form the basis of future regulations.

i. Policies and management

Public health authorities, such as the minister of health and DINEPA, must, through a joint effort, develop optimal policies and establish enforcement for drinking water businesses in Haiti. These regulations should include, but not be limited to, drinking water facilities/kiosks operations and maintenance, drinking water testing, water treatment facilities location, and raw water sources.

CHAPTER FOUR: PRICING DRINKING WATER TESTING IN NORTHERN HAITI: FINANCIAL SENSITIVITY TO OPERATING COSTS, USER DEMAND, AND ECONOMIC CONDITIONS

Abstract

Safe drinking water availability is a concern in Haiti. Public systems have limited coverage and reliability. Private wells and local water sources are often of unknown or poor quality. Public health events, such as the 2010 cholera outbreak, demonstrate vulnerability to water contamination. To address these concerns, a drinking water laboratory was established at the Campus Henri Christophe in Limonade, a branch of the State University of Haiti, to meet water testing demands from local clients such as for-profit kiosks, institutions, industries, and municipal water systems operating in the Northern Corridor. This study assessed the financial viability of a university-based drinking water laboratory in Haiti by calculating Internal Rate of Return and Net Present Value. Sensitivity analysis was used to identify the range of conditions under which laboratory revenues would cover operating costs. To achieve an acceptable profitability level, the laboratory must perform microbiological testing for routine monitoring samples and test an average of five samples per day. Price-based incentives for new clients have relatively small impacts of profitability whereas lowering the number of daily samples performed has a high impact on the projected Internal Rate of Return. Finally, international and Haitian inflation cause substantial variation in profitability. These economic factors will be among the key drivers of laboratory operation costs. The results underscore the main factors that must be considered to make the laboratory successful and the importance of strategic marketing for laboratory managers to encourage clients to regularly test drinking water and emphasize microbiological testing.

4.1. Introduction

Unsafe drinking water, along with poor sanitation and hygiene, is the main contributor to an estimated 4 billion cases of diarrheal disease annually, causing 1.8 million global deaths, mostly among children younger than five (McLaughlin et al., 2008). Of all the pathogens causing diarrhea, *Shigella* species, *V. cholera, C. jejuni,* and *C. difficile* are of most concern (Sack et al., 1997). Over the past decades in Haiti, inhabitants have suffered from waterborne diseases due to chemical and microbiological contamination of drinking water (Farone et al., 2011; Singer, 1994; Allaire et al., 2018; Rivera-Núñez et al., 2018b). Haiti experienced a cholera outbreak in 2010. The disease reached all ten provinces in Haiti and spread to the neighboring Dominican Republic (Chin et al., 2011). To reduce drinking water issues after the cholera outbreak, private-sector kiosks became increasingly important. These neighborhood units typically operate as franchises of provider companies. They often use reverse osmosis (RO) membrane filtration and offer treated water for sale in one- or five-gallon units (Patrick et al., 2017c).

Over 90% of water samples from for-profit kiosks in Port-au-Prince met World Health Organization (WHO) microbiological guidelines at the point of sale in samples taken about 12 months after first operation (Petter et al., 2020). Nonetheless, 9.1% tested positive for *E. coli*, which is an indicator of fecal contamination and vulnerability to waterborne disease. The presence of *E. coli* indicates increased prevalence of diseases such as typhoid, with the burden falling disproportionately on low-income households (Lantagne & Clasen, 2013; MSPP, 2014). The cost of treating a case of typhoid in Haiti is typically US $300 (MSPP, 2014).

Microbes can persist in some chlorine-treated water, so drinking water should be tested frequently for residual chlorine and fecal coliforms. Good practice for kiosk owners is to regularly test drinking water to ensure its safety. While regulations can mandate testing (Patel et al., 2020), it is unlikely that establishment and enforcement of drinking water regulations will occur in Haiti, so market-based solutions are required. Private kiosks whose water is regularly tested and certified may have a marketing advantage. Wells individually owned or shared by clusters of private residences also require periodic water testing (Liang et al., 2021; Crane, 1994). Testing should be done by capable and reliable laboratories that provide competent interpretation by trained personnel (Greenberg & Hausler, Jr., 1981).

Most actions to address these concerns have been taken in the central and western parts of the country with few interventions in the northern regions despite there being large and vulnerable populations. With a population of 253,617, the annual total expenditures for typhoid treatment during an outbreak in the city of Cap-Haitian could be up to US $38.8 million (MSPP Haiti, 2011; Jaramillo & Sancak, 2007). Additionally, hazardous chemicals are present in the region. In Trou du Nord and Caracol communes, both near Cap-Haitian, the arsenic concentration was above the drinking water standard of 10 μg/L set by the National Directorate of Drinking Water and Sanitation/Direction Nationale de l'Eau Potable et de l'assainissement (DINEPA) (Bundschuh et al., 2021; Rivera-Núñez et al., 2018).

4.1.1. Need for testing services

Haiti does not have a functional water testing laboratory in the Northern Corridor. The Spanish government development agency is working with the Office Régional de l’Eau Potable et de l’Assainissement/Regional Office of Drinking Water and Sanitation (OREPA) to establish laboratories in Gonaïves (OREPA Centre) in central Haiti and in Les Cayes (OREPA Sud) in southern Haiti, but neither is currently operational. Two water testing laboratories operate in Port-au-Prince, one at DINEPA and the second at the State University of Haiti-Damien (Stoa, 2021). However, conditions in Haiti make it difficult for kiosk operators to utilize a laboratory in another city (Ogisma et al., 2021), and testing fees are expensive (Pinto et al., 2016). Additionally, the available testing services often lack skilled staff to conduct analyses, interpret results and make recommendations (Williams et al., 2015). Government agencies have inadequate infrastructure and often lacking funds to maintain reagents and instrumentation (Wampler & Sisson, 2011c). The development of water testing services can contribute to better health and well-being for the broader population (D. Lantagne & Clasen, 2013b).

To respond to drinking water testing needs, a laboratory was established through a collaborative effort among the US Agency for International Development Water and Sanitation (USAID-WATSAN) project in Haiti, the State University of Haiti branch Campus Henry Christophe in Limonade (CHCL), and Auburn University. It was implemented in the Northern Corridor to serve the populations of Cap-Haitian, Quartier Morin, Milot, Caracol, Trou du Nord, and Limonade. In these municipalities, the absence of treated tap water leads families to purchase bagged water, bottled water, and water from for-profit private kiosks. Low-income families often obtain water from shared wells, springs, streams, or other sources followed by traditional treatment methods using either aloe vera or lime for disinfection. The laboratory is also intended to build the capacity of local drinking water technicians and increase the availability of water testing in the Cap-Haitian area. The laboratory service is intended to monitor drinking water sources to ensure safety for public health and enhance consumer confidence (Fraulin et al., 2021).

4.1.2. Projecting financial viability

In the Northern Corridor, water providers have never participated in drinking water testing, which, paired with the inadequate infrastructure of government agencies, could impede lab profitability (Wampler & Sisson, 2011c). To ensure the sustainability of the drinking water laboratory over a five-year horizon of operation, it is critical to anticipate the cost of testing, client demand and willingness-to-pay, and the potential effects of broader economic changes (McLaughlin et al., 2008). Few consumers and business owners seem fully aware of the relevance of drinking water testing. Thus, a persuasive marketing strategy could increase the use of testing services and enhance the financial viability of the laboratory (Morgan, 2012). Further, sudden currency fluctuations and inflation also may affect demand for tests and laboratory cost structures (Ivanova et al., 2000).

Prior literature has evaluated improving drinking-water quality in developing nations. For example, Boukhari shows the economic challenges of achieving financial sustainability for water sanitation and supply firms in Algeria (Boukhari & de Miras, 2019). Other studies have focused on the potential to establish water testing facilities. Delaire et al. use data from water monitoring facilities across fifteen sub-Saharan African nations to analyze microbiological water quality testing costs (Delaire et al., 2017). The authors find that annual facility costs differ immensely across nations, which is in part dependent on varied sizes of population served by the facilities. Similarly, Crocker and Bartram compare the costs of water monitoring in seven countries throughout the world (Crocker & Bartram, 2014). They conclude that sample transportation and labor represent three-quarters of the marginal costs, showing the limitations of fixed-location laboratories. In Haiti specifically, a couple studies have evaluated the efficacy of low-cost methods to test drinking water quality (Singer, 1994) and treat drinking water in households (Murray, 2020). However, while existing literature has provided valuable insights regarding certain economic aspects of water-quality monitoring, it has yet to evaluate the economic viability of supporting a water-quality testing laboratory in developing nations. This is especially true in Haiti, a country that has faced grave waterborne illness outbreaks in recent years.

In Haiti, anticipating cost increases is especially important for ensuring financial viability due to the dependence on imported reagents and supplies (Onyeonoru, 2005). The internal rate of return (IRR) will be used to assess if the laboratory is profitable relative to costs and benefits by using capital budgeting to create accountability (Gafli & Fauzi, 2019). Sensitivity analysis of the capital budget will identify the key variables determining profitability, investigate their impacts, assess the project potential losses, and identify preventive actions to mitigate possible negative effects (Han et al., 2014). IRR is one indicator of the usefulness of an investment. IRR has been extensively used for the appraisal of public investment decisions (Tilak, 2021). Other risk-analysis methods for the identification of critical threats to financial viability could suggest necessary management decisions (Cárdenas et al., 2014).

In this paper, we analyzed the profitability of the drinking water laboratory at CHCL over a five-year period. To focus the analysis, we considered different increments of daily sample demand from different potential clients, the combination of tests performed on each sample, and different test pricing schemes. Finally, we assessed the sensitivity of profitability to an international chemical pricing index and Haitian inflation. Sensitivity analysis suggests strategies that laboratory management might undertake to ensure profitability.

4.2. Conceptual framework

This analysis explores scenarios under which a drinking water treatment laboratory would be economically viable in Haiti. In our setting, the water testing laboratory charges kiosks, municipalities, and other entities for testing services for various aspects. Thus, the firm's profit equation is as follows:

$$\pi = P(Q) * Q - cQ(P) - FC, \tag{1}$$

where *P* is a vector of prices charged for the tests offered by the laboratory, Q is a vector of client demand for each type of test provided and is a function of the prices charged by the laboratory, *c* is a vector of prices for chemicals used on each test, and *FC* are the fixed costs of production.

4.2.1. Estimation of $\boldsymbol{NPV}$ and $\boldsymbol{IRR}$

The laboratory project was evaluated using the IRR and Net Present Value (NPV), two measures often used to determine whether an operation is economically viable (Percoco, 2012). Specifically, the NPV is defined as:

$$NPV\ (I, R_1, \dots, R_T, \rho, T) = I + \sum_{t=1}^{T} \frac{R_t}{(1+\rho)^t}, \tag{2}$$

where $I < 0$ are the laboratory investment costs occurring at time $t = 0$ (May 2022), R_t is the cash flow or net benefit occurring at time t, ρ is the discount rate, and T is the evaluated lifetime of the project in years (T=5 in our setting). According to the NPV rule, a project is profitable and should be undertaken only if $NPV(I, R_1, \dots, R_T, \rho, t) > 0$. The cash flow ($R_t$) is equal to *Net Income + Depreciation + Stock Based Compensation + Deferred Tax + Other Non-Cash Items – Increase in Accounts Receivable – Increase in Inventory + Increase in Accounts Payable + Increase in Accrued Expenses + Increase in Deferred Revenue.*

Alternatively, one can compute the IRR, which is the rate for which the sum of accumulated discounted values of all inflows is balanced numerically by the sum of the accumulated discounted values of all the outflows at the end of the project, including the investment cost (David Promislow & Spring, 1996). In other words, the IRR is the minimum rate of return the project must obtain to be worth undertaking. Formally, the IRR is defined as the value r such that

$$NPV\ (I, R_1, \dots, R_T, r, T) = I + \sum_{t=1}^{T} \frac{R_t}{(1+r)^t}, \tag{3}$$

From equations 2 and 3, the project is profitable if $r > \rho$, thus the IRR and NPV both provide equivalent evaluation criteria (Percoco, 2012).

The investment decision involves the use of valuation models that require the estimation of the investment cash flows. These feed into the economic decision criteria (NPV and IRR) (Borgonovo & Peccati, 2006).

4.2.2. Sensitivity analysis

The valuation criteria used (NPV and IRR) are based on deterministic values, so we use sensitivity analysis techniques to understand how results vary from the base case under deviations of the assumed parameters (Horowitz, 1998). This is because both the NPV and IRR, hence profitability, are affected by several exogenous factors whose values are not known with certainty (Ravalico et al., 2010). These include variables such as prices of chemicals and other inputs and demand for laboratory services. One method of local sensitivity analysis uses the differential importance measure (*DIM*) (Borgonovo & Peccati, 2004).

We will focus on the IRR, as that is the measure of focus in our analysis. We define IRR as a function of exogenous parameters, such that

$$IRR = f(x) \tag{4}$$

is a differentiable function in $X = (x_1, \ldots, x_n)$, a matrix of input parameters (Percoco, 2012). The following DIM is defined as

$$D_s = \frac{(\partial f / \partial x_{\mathrm{s}})\mathrm{d}x_{\mathrm{s}}}{\sum_{j=1}^{n}(\partial f / \partial x_j)\mathrm{d}x_j}\,, \tag{5}$$

where D_s measures the exogenous variable importance by the ratio of (1) the change in the IRR following a change in x_s, and (2) the sum of the changes in F induced by changes in all the exogenous variables.

The partial derivative of an IRR with respect to inflation and another variable shows the increments of IRR units. However, the partial derivative of the IRR with respect to a cost also is a pure number. Therefore, one cannot compare the two partial derivatives to establish whether inflation is more important than costs (Borgonovo et al., 2010). Further, the NPV is expected to be very sensitive to the level of service demand in the laboratory, which is unpredictable or highly probabilistic due to the novelty of the laboratory (Borgonovo & Peccati, 2004). When the degree of novelty increases due to complexity and dynamics in the water testing demand, probabilistic approaches would not be sufficient to predict and manage future events that could relate to the demand for water testing (Brouwer & De Blois, 2008).

Finally, many systems test sensitivity to different capital and recurrent costs and the selling price of raw materials. These analyses show that change in final selling price is more sensitive to NPV than change in investment and recurrent costs (Svatoňová et al., 2015). Further, both internal and external marketing programs have a significant impact on employees' commitment, external consumers, their market motivation, and the overall profitability of businesses (Zaman et al., 2012).

The motivation may be effective while providing some incentives (Poitevin, 2000) that could increase kiosks' owners ability to order water testing services by lowering the unit aspect price (Kane et al., 2004). Due to the willingness to pay water testing according to the findings in chapter three will be motivated only by mandatory, some incentives price-based could motivate water vendors. Furthermore, political crises that are recurrent in Haiti are a crucial source of inflation that could affect the price of laboratory consumables (Ogisma & Carrasco, 2007).

4.3. Method

4.3.1. Study area and target population

The CHCL laboratory in Limonade, near the major city of Cap-Haitian, is intended to serve the Northern Corridor department of Haiti. The Northern Corridor is bounded by the Dominican Republic to the east, by the departments of Centre and Artibonite to the South, by the Northwest department to the west, and by the Atlantic Ocean to the north. Kiosk vendors have become an increasingly important provider of drinking water to the Haitian population since the 2010 earthquake and subsequent cholera outbreak (Patrick et al., 2013b).

Kiosk owners are the primary target users of the laboratory, but testing will also be available to municipal governments, nongovernmental organizations (NGOs), and other users. The closest municipalities where most kiosk owners could take drinking water samples to the laboratory are Cap-Haitian, Quartier Morin, Milot, Limonade, Trou du Nord, and Caracol. These municipalities have estimated travel times to Limonade on shared transportation services that are less than the maximum sample holding time for microbiological testing as demonstrated in chapter two in this dissertation. Additionally, Ouanaminthe and Fort Liberty are economic hubs in the Northern Corridor in which water providers could develop partnerships with the laboratory and transport samples by private vehicle. The population of these eight municipalities is 357,000. The focus should be on Cap-Haitian because the highest demand will come from this large municipality where most residents purchase drinking water from privately-owned kiosks.

Cap-Haitian has struggled to develop sufficient water services (Martinez, 2019b). Although investments in the sector have increased significantly in recent years, the sustainability of drinking water services remains fragile and uncertain (Martinez, 2019b). Water sources are not being adequately protected and this problem is exacerbated by the rate and nature of urban expansion in the country, with growth in suburban areas with no sanitation services (Martinez, 2019b). For suburban households, springs are a common water source. Chapter two of this dissertation demonstrated that the presence of springs in a community has a significant positive correlation with cholera infection rates in the Northern Corridor. In terms of the institutional context, the sector suffers from the absence of effective and clear legislation to define the roles and responsibilities of stakeholders according to the DINEPA Regional Director (A. Pascal, Personal communication, November 2021).

4.3.2. Testing plan

The recommended chemical test parameters for water sources in Haiti that can be completed by the CHCL lab are arsenic, fluoride, lead, manganese, nitrate, and nitrite. Each water source should be tested individually for these parameters. Physical tests for pH, conductivity, turbidity, and total dissolved solids (TDS) can also be completed by the lab. These chemical and physical parameters are unlikely to change suddenly, so annual testing of untreated source water is recommended. The exceptions are surface water and shallow well sources near farms, which may require more frequent testing for nitrate and nitrite, and water distributed through older piping systems, which should be tested for lead. The key monitoring tests for treated water are chemical testing for residual and total chlorine and microbiological testing for total coliforms and *E. coli*. These tests ensure that water is adequately disinfected. The WHO recommends that routine microbiological testing to ensure sanitary conditions in piped water systems be performed monthly. While the CHCL lab is equipped to perform chlorine testing, field testing may be preferable for larger water providers. The holding time for chlorine samples is short (< 2 hours), and frequent (weekly to daily) testing is a reliable way to ensure proper water treatment.

4.3.3. Empirical Application: CHCL Laboratory Profitability

i. Variables

The laboratory offers a menu of tests reflecting its capabilities and user needs. The physical tests performed are pH, conductivity, TDS, and turbidity. The chemical tests performed are arsenic, fluoride, lead, nitrate, nitrite, manganese, and residual and total chlorine. Additionally, microbiological analysis through membrane filtration can be performed and provides the client with a quantitative assessment of total coliforms and *E. coli* present in the sample. Expenses will be incurred to perform these tests. International and Haitian inflation are two relevant variables that will affect lab costs and profitability through IRR. International chemical index data from ChemIndex was used, which measures average annual changes in chemical prices (Hubbard, 2021). Haitian inflation data was taken from the Institut Haitien de statistique et d'informatique/Haitian Institute of Statistics and Informatics (IHSI) (MEF, IHSI, 2015). The potential demand from various client categories is also considered.

ii. Projected water testing demand

The potential water testing demand was estimated based on the main sources of water in Cap-Haitian according to a 2020 water assessment conducted by the US Agency for International Development (USAID) (USAID, 2020). The most common source (31.9%) is protected wells at the household level used for any needs. The expected water testing demand will come from potential clients in the Northern Corridor. The potential water testing demand from each category of clients was estimated by the USAID-WATSAN project team and laboratory managers with input from stakeholders involved in the sector. The expected number of tests per month from each type of client are three from NGOs, ten from schools and universities, 25 from household well owners, 15 from municipal water services, 40 from for-profit kiosks, and four from industrial clients. This gives a total of 96 samples per month. Both training and testing services will be part of the laboratory’s mission. We assume one laboratory technician training session per month providing $2,000 in income.

iii. Testing fees and revenue

Based on the potential clients, a conservative total of 96 samples per month is used, or around five tests per day. To start, prices have been set up according to the type of test: $8.96/test for physical tests, $15.37/test for chemical tests, and $11.95/test for microbiological tests based on pricing at the DINEPA drinking water laboratory in Port-au-Prince. If all 11 parameters are tested on each of the 96 samples, the revenue for drinking water testing is estimated to be $5,827 per month. To compensate for any cost increase, the actual test fees may be set higher than these initial fees.

iv. Operation costs

Depreciation costs are first deducted from the gross margin to get net income, then treated as not disbursed. These are added financial fluxes to get the cash flow to measure the long-term sustainability for a 5-year period. Full details for one-year operation costs are given in Table 4.1. Determining operation costs is critical to ensure enough cash is available to begin laboratory operations within the budgeted time frame as well as within the cost budget. Operation costs typically fall within two categories: monthly costs and one-time costs. Monthly costs occur throughout the existence of the laboratory, and one-time costs are incurred once during the startup period.

Table 4.1. First-year laboratory operation costs in U.S. dollars.

Items	Months	Cost per Month	One Time Costs	Total Cost
Advertising/Marketing	3	$500	$500	$2,000
Technician Salaries	12	$800	$0	$9,600
Postage/Shipping	12	$30	$25	$385
Communication/ Telephone	12	$25	$20	$320
Computer Equipment	12	$20	$0	$240
Insurance	12	$50	$60	$660
Bank Service Charges	12	$5	$0	$60
Supplies	12	$10	$0	$120
Travel	12	$20	$0	$240
Cash-On-Hand (Working Capital)		$0	$100	$100
Miscellaneous		$0	$100	$100
Estimated Operating Budget				$13,825

v. Local inflation and international chemical index

The inflation rate provided by IHSI from 1986 to 2020 is on average 12%, indicating the price of local goods and services may increase 12% annually over the five-year period (Table 4.2). Additionally, the average annual international chemical index is 6% over the period from 1985 to 2020 meaning that the laboratory is likely to face some inflation in the cost of laboratory supplies over the five-year period. The analysis assumed that over the five-year period of operation, CHCL will annually supply the laboratory with chemicals and purchase local goods and services.

Table 4.2. Annual Haitian inflation rate and chemical international index

Local Inflation Over 35 Years		Chemical International Index Over 37 Years	
Inflation Rate	Frequency	Index	Frequency
Less than 10%	0.34	Less than 10%	0.65
10% – 20%	0.37	10% – 20%	0.22
20% – 30%	0.23	Greater than 20%	0.13
30% – 40%	0.03		
Greater than 40%	0.03		

4.3.4. Sensitivity analysis

We examined many dimensions of variability in water testing services: the number of samples, the types of tests ordered for each sample, the average fees per test, the number of samples received daily or monthly, local inflation, and the international chemical price index. The focal outcome or dependent variable is the IRR. The IRR is computed from the net cash flow over the 5-year period. Since the initial costs are given, we estimate an IRR for which the sum of total costs and total discounted net incomes will be zero, as is the IRR by definition. The profitability of each test offering is estimated based on its IRR. USAID normally employs a discount rate of 12% as a decision standard. That is, an IRR greater than 12% is required for the project to be profitable. The sensitivity analysis examines test demand variations on the profitability of the drinking water lab as a business developed at CHCL. Analyses were performed in Microsoft Excel 16.0 and all values reported are in US dollars.

4.4. Results

4.4.1. Laboratory profitability and risk factors

i. Depreciation Costs

The drinking water lab was equipped with an autoclave, incubator, refrigerator, and a solar power system to supply 24-hour electricity. In total, 53 small equipment items, 11 large equipment items, and 139 items for power supply were purchased for a complete operational drinking water lab. The total cost of equipment is $63,746, leading to an average annual depreciation cost of $7,281. The lifetime of scientific equipment is 5 years for small equipment; 15 years for large equipment; 5 years for batteries and accessories; and 25 years for solar panels (Nasmus Sakib khan Shabbir & Liang, 2018).

ii. Profits

For the first year of operation, we predict $5,770 in gross revenues each month with full testing and $5,740 gross revenues each month during initial lab set-up when only chlorine and microbiological testing will be performed. We assume full operation of the drinking water lab over the year with no political crises or natural disasters affecting lab activities. During the first six months of operation, a discount of 50% will be applied for any testing requests for all clients. This marketing strategy is intended to encourage new clients to begin using the lab and was used successfully during the establishment of a soil testing laboratory at CHCL (O. Jean, Dean, personal communication, July 2021). The gross revenue over the year is $54,452 and the net income is $21,415 for the first year. However, for the second year, full pricing will be applied. Therefore, the net income will increase to $36,567.

iii. Assumptions for sustainability

The long-term sustainability assumption is that the equipment-based lifetime costs will be covered to generate a positive NPV and high IRR. When these net cash flows have satisfied the required conditions, the project is economically or financially beneficial. The full results are in Table 4-3. and demonstrate that the cash flow will be positive over a five-year period. In this initial analysis, we assume that four samples will be received every day for microbiological and chlorine testing and other physical and chemical tests will be performed for each client once per year. Over the next five-year period, the drinking water testing lab will generate a positive NPV of $44,434 and an IRR of 38%, greater than the 12% discounting rate (Table 4.3). Based on no refund for capital or interest and both IRR and NPV values, we anticipate long term sustainability for the drinking water testing lab at CHCL (Table 3.3).

Table 4.3. Cash-Flow: Net present value (NPV) and internal rate of return (IRR).

REVENUE	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Grants and Equity	($63,746)					
Gross Revenues		$54,452	$71,690	$71,690	$71,690	$71,690
Initial Equity	$0	$0	$0	$0	$0	$0
Total Initial Investment	($63,746)					
Total Gross Revenues		$54,452	$71,690	$71,690	$71,690	$71,690
EXPENSES						
Chemicals and Supplies		$7,270	$7,634	$8,016	$8,416	$8,837
Gross Margin		$47,182	$64,057	$63,675	$63,274	$62,853
Fixed Costs		$28,661	$28,661	$28,661	$28,661	$28,661
Financial fees/Interest costs		$3,187	$3,187	$3,187	$3,187	$3,187
Return before tax (1)	($63,746)	$15,334	$32,209	$31,827	$31,427	$31,006
Reinvestment Based-Equipment Lifetime (2)			($1,722)	($1,722)	($4,486)	($4,486)
Depreciation costs (3)		$7,281	$7,281	$7,281	$7,281	$7,281
Balance (1) +(2) +(3)	($63,746)	$22,615	$37,767	$37,386	$34,221	$33,800
Working Capital		($1,200)	($1,200)	($1,200)	($1,200)	($1,200)
Cumulative Cash-Flows	($63,746)	$21,415	$36,567	$36,186	$33,021	$32,600
Net present value and internal rate of return (Discount rate of 12%): Cash flow for sustainability						
		YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
Cash balance	($63,746)	$21,415	$36,567	$36,186	$33,021	$32,600
Present Value of Cash-Flow	($63,746)	($42,331)	($5,763)	$30,422	$63,443	$96,043
Financial NPV	$44,434			Financial IRR		38%

4.4.2. Sensitivity analysis

i. IRR and related risks

First, we consider the scenario in which all clients request a standard testing plan with a full suite of chemical tests performed annually on source water and monthly testing of treated water. If only residual chlorine testing is performed on treated water, the laboratory will not be profitable with an *IRR* of -21%. However, if microbiological testing is also performed, as recommended by the WHO, the *IRR* will be 38%, greater than the USAID requirement of 12%. Even if clients request a limited set of chemical tests annually based on site-specific concerns, the

IRR will be at least 38% if microbiological and chlorine tests are performed. If this testing plan is followed, there will be a profitable *IRR*. In addition to these tests, basic physical tests (pH and conductivity) will likely be run on some samples that come into the lab, which will keep the *IRR* over the required level.

We analyzed how the number of treated water samples received daily for routine testing could affect the projected IRR. A high number of samples per day is expected if clients test their water frequently. The profitability could be as high as 163% with the laboratory operating at its full capacity of 12 daily samples with microbiological testing of all samples (Figure 4-1). Based on preliminary market analysis, we expect that three or four daily samples is the most realistic, providing an IRR of 18% and 38%, respectively. Given several daily samples, the addition of microbiological testing increases the IRR by 12% per unit water sample. When microbiological tests are performed, the expected IRR increases from 18% to 104% when the number of daily samples increases from 3 to 8. The IRR risk related to microbiological tests, for the sample range from 3 to 12, is 145% showing the relevance of this test to profitability. In conclusion, microbiological tests and sample demand are crucial for the profitability of the laboratory.

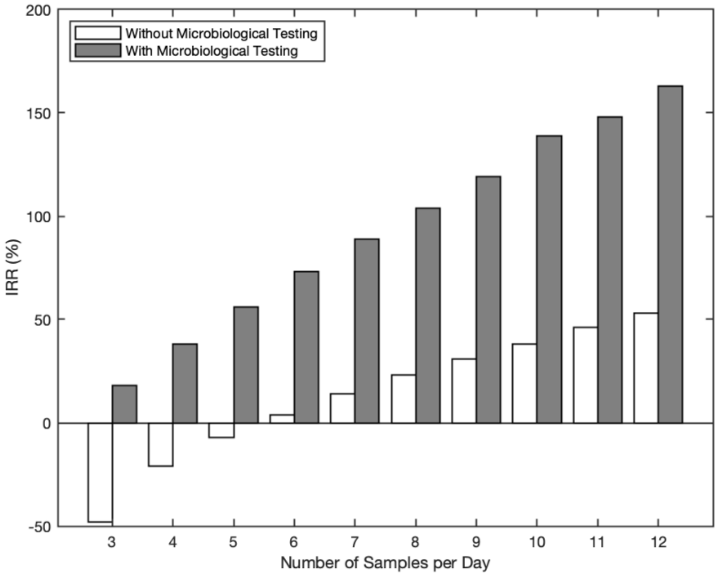


Figure 4-1. Sensitivity of IRR to the number of samples received per day with and without microbiological testing.

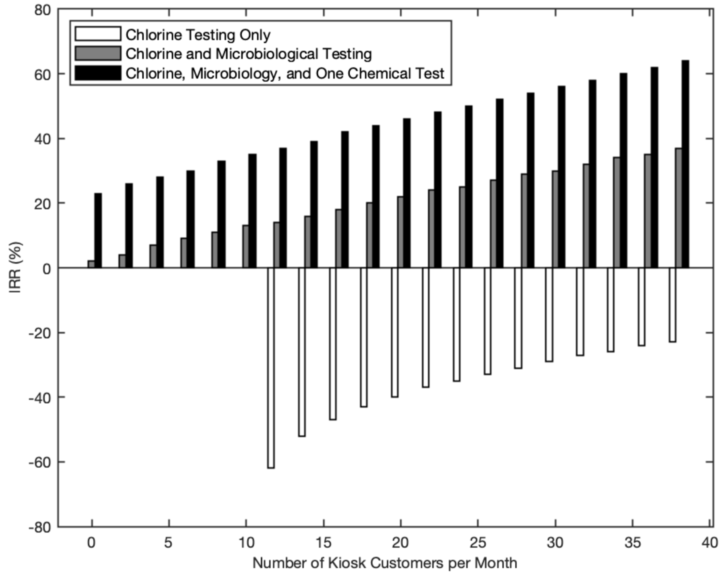


Figure 4-2. Sensitivity of IRR: monthly testing demand from kiosks with/without microbiological testing and one chemical test

For-profit kiosk owners are the largest group of laboratory clients and safe water from kiosks is key to preventing waterborne illness among vulnerable populations. We considered the effect of demand from this market segment. Simulation results in Figure 4.2 shows that 20 monthly samples from kiosks with only chlorine testing will provide an *IRR* of -40% whereas 20 monthly samples with consistent chlorine and microbiological testing will provide an *IRR* of 22%. The laboratory must receive at least 12 samples per month from kiosk owners to maintain profitability. However, if clients routinely request one additional chemical test, which may include nitrate testing that is recommended for water sources near agricultural areas, the laboratory could be profitable without for-profit kiosk owners as clients demonstrating an alternate strategy to achieve profitability.

ii. Price Strategies

We analyzed how pricing strategies will affect sustainability. The change in microbiological unit price has a low risk on the projected *IRR*. The projected *IRR* will be 10% and 29% for a pricing of $9.50 based on three and four samples per day, respectively (Table 4.4). A pricing level of $10.50 will provide 13% and 33% of profitability for three and four samples per day, respectively. The testing fees have some effect, but it isn't as large as the effect of clients not ordering microbiological tests or sample demand. Therefore, reducing prices to increase water testing demand could be among the best strategies to make the lab financially viable.

Table 4.5 demonstrates that the lab can be profitable under a range of values for chemical price index, which indicates international inflation, for daily sample numbers greater than or equal to four. For a Haitian inflation up to 35%, processing four samples per day will keep the projected *IRR* greater than 12% whereas for five samples per day the projected *IRR* will always be greater than 12%, even for a Haitian inflation level up to 40%. Local inflation, which can be up to 46% in Haiti, will severely hinder the profitability of the drinking lab if fewer than four samples are received per day. While inflation rates are outside of the control of the laboratory management, marketing to maintain a reasonable daily sample demand can ensure the profitability of the lab under a range of conditions.

Table 4.4. Sensitivity of IRR to microbiological testing fees and daily sample demand.

Testing Fees (USD)	Number of Samples processed per Day					
	3	4	5	6	7	8
$6.00	-4%	14%	28%	42%	54%	66%
$6.50	-2%	16%	31%	45%	57%	69%
$7.00	0%	18%	33%	47%	60%	73%
$7.50	2%	20%	36%	50%	63%	76%
$8.00	4%	23%	38%	53%	66%	79%
$8.50	6%	25%	41%	55%	69%	82%
$9.00	8%	27%	43%	58%	72%	86%
$9.50	10%	29%	45%	60%	75%	89%
$10.00	12%	31%	47%	63%	78%	92%
$10.50	13%	33%	50%	66%	81%	95%
$11.00	15%	35%	52%	68%	83%	98%
$11.50	17%	37%	54%	70%	86%	101%
$12.00	18%	38%	56%	73%	89%	104%

Table 4.5. Sensitivity of IRR to Haitian inflation and the International Chemical Index.

Haitian Inflation Rate (%)	Three Samples per Day					Four Samples per Day					Five Samples per Day				
	International Chemical Price Index (%)														
	5	9	13	17	21	5	9	13	17	21	5	9	13	17	21
5	15	14	13	11	10	36	35	34	33	32	54	53	52	52	51
10	12	11	10	8	6	33	32	31	30	29	51	51	50	49	48
15	9	8	6	5	3	31	30	29	28	26	49	48	48	47	46
20	6	5	3	1	-1	28	27	26	25	23	47	46	45	44	43
25	3	1	-1	-3	-5	25	24	23	22	21	44	43	43	42	41
30	-1	-2	-4	-7	-10	22	21	20	19	18	42	41	40	39	38
35	-4	-6	-8	-11	-14	20	19	17	16	15	39	38	37	37	36
40	-8	-10	-13	-16	-20	17	16	14	13	11	37	36	35	34	33

4.5. Discussion

We analyzed how water testing demand, the types of tests requested, and Haitian and international inflation will affect the profitability of the drinking water lab through financial sensitivity analysis. Even though inflation poses less risk than the other factors, it remains very challenging for a laboratory in a location like Haiti. The IRR volatility related to Haitian inflation is similar to the results of studies of price volatility and the market overreaction during the political crisis triggered by the controversial Taiwanese election of 2004 (Huang et al., 2011). It was shown that companies with better corporate governance or performance experienced less price volatility and less increase in volatility during such a crisis. Therefore, the laboratory should establish a clear and transparent management and governance plan.

Our analysis demonstrated low potential impacts of international inflation on the IRR, making the risk related to this economic factor relatively weak. However, the prices of imported commodities or related manufactured products from China, which the lab is heavily dependent on, are strongly connected with global commodity prices (Tang et al., 2014). Further, the profitability of the laboratory is highly elastic to the demand for water testing samples, so a price incentive strategy may be best for profitability. This result is consistent with wind electricity in China, where achieving effective outcomes required a price incentive policy (Zhang et al., 2016).

As for-profit kiosks are the largest potential client group, emphasis should be on maximizing the number of kiosks that have requested testing to increase testing demand and laboratory productivity (Culbreath et al., 2021). We have seen in chapter three that lowing the testing price could be good incentives for water testing. However, only testing mandatory is relevant factor to encourage water vendors to test the water. Unfortunately, there is no law enforcement in Haiti that could make mandatory effective. Laboratory manager could play on good marketing plan, however, advertising has not always been shown conclusively in enhance the value of a business (Kundu & Kulkarni, 2008). Therefore, the drinking water laboratory manager in Limonade must develop smart marketing to ensure consistent demand throughout the year to keep the laboratory profitable. Better understanding of the factors that drive demand for water testing in Haiti will be crucial. Additionally, networking will play a key role in promoting water testing, because the presence of social networks generally lead to higher adoption rates of novel technologies (Dupont, 2010). Laboratory staff should seek speaking opportunities at conferences, fairs, and other venues where water companies and kiosk operators congregate to present the importance of water testing and the services provided by the laboratory. Social media will play a growing role in communicating lab capability and functions to prospective users. Finally, the estimate of the annual expenditure to treat a waterborne disease outbreak is about $38 million for the Cap-Haitian population. By comparison, the estimated investment and operation costs for establishing a drinking water laboratory are $63,746 and $13,823, respectively. This indicates that there are substantial economic benefits to successfully increasing water testing in the Northern Corridor of Haiti.

4.6. Conclusion

Daily testing demand, requests for microbiological testing per sample, and providing price-based incentives are the main factors that determine profitability of the CHCL drinking water laboratory. The chemical international pricing index and Haitian inflation rates may also affect laboratory profitability, but to a lesser extent. Sensitivity analysis indicated that when inflation is considered, an average of five samples received per day for routine microbiological and chlorine testing will allow the laboratory to be profitable under most scenarios. To ensure the cost-effectiveness of the operation, laboratory staff must initiate and follow a marketing plan that includes brochures, instructional leaflets, and radio announcements as relevant tools to communicate laboratory capabilities and procedures to customers with a particular focus on for-profit kiosk owners. The sensitivity of IRR to pricing was low, so providing price incentives to increase demand will be an effective strategy. The laboratory staff must provide leadership to these efforts.

CHAPTER FIVE: CONCLUSIONS

5.1. Introduction

Haiti has faced a perpetual lack of sanitation, so ensuring the safety of drinking water in both remote areas and cities is crucial to preventing waterborne disease outbreaks. The establishment of for-profit drinking water kiosks after the 2010 cholera outbreak to supply safe drinking water to households across a range of incomes level has improved wellbeing. However, surveys with water vendors demonstrated poor maintenance of the kiosk water and insufficient chlorine levels for disinfection. Therefore, regular water testing by water treatment facilities managers is key to identifying unsafe water systems and preventing epidemics. The main goal of this dissertation is the assessment of potable water in the Northern Corridor in Haiti. For that, we assessed the community level factors contributing to cholera infection rates in the Northern Corridor in Haiti, appraised the kiosk water quality and kiosk vendors' willingness to regularly test the water sold at kiosk level and, finally, determined the economic factors that could hinder the sustainability of a drinking water testing laboratory established in the Northern Corridor to ensure safe drinking water availability.

5.2. Conclusions

This section provides an overview of each main chapter, including the general background, summary of key findings and relevant plans that should be adopted, possibly through funded projects and regulations, to support safe drinking water in the Northern Corridor and the country. Secondary and primary data were used in statistical analyses and water testing were performed at the drinking water laboratory established at Campus Henry Christophe of Limonade (CHCL) to assess for-profit kiosk water sold in the municipalities of Cap-Haitian, Limonade, and Quartier Morin.

5.2.1. Community-level factors and safe water testing access in Northern Haiti

Due to low availability of piped water in Haiti and the absence of water testing in the Northern Corridor, residents have obtained their water from springs, rivers, lakes, and lagoons for household use and drinking. In remote areas, there is limited access to purchase chemicals for drinking water treatment or drinking water testing. There is a need to identify which remote communities are most vulnerable to waterborne disease outbreaks to prioritize services. The second chapter of the dissertation analyzed the correlations between water body types of present, socioeconomic factors and cholera infection rate in municipalities in the North and Northeast departments. Further, this chapter assessed the travel time to take water samples to the drinking water testing laboratory established at CHCL.

The research filled this gap and demonstrated that the presence of springs in a community is significantly associated with cholera infection rate based on correlation and regression analysis. Rivers, lakes, lagoons, and coastline were not significantly correlated with cholera infection. Additionally, the analysis showed that travel time to a laboratory cannot be predicted from distance alone. Poor road conditions and large elevation change can substantially increase travel time. These results support hypotheses *i* and *ii* of this dissertation. It may be beneficial to consider targeting communities where springs are present for small laboratories or field-based testing and emphasize safe use and protection of these water sources. Even though socioeconomic factors play a key role in health outcomes at the individual and household level, our correlation analysis did not find a significant relationship between these metrics and cholera infection rate at the community level in the Northern Corridor. While cholera prevention programs should target vulnerable groups within a community, the community-level socioeconomic indicators analyzed in this study do not appear to be useful for prioritizing testing resources.

5.2.2. Vendor willingness to test drinking-water in Northern Haiti

The for-profit water kiosks that have been established to supply safe drinking water in Haiti source raw water from springs and wells, which are exposed to environmental bacteriological contaminants. Since their establishment in the Northern Corridor, no research has addressed the quality of the water sold due to the absence of a drinking water testing laboratory in the region. Further, there is a lack of understanding of kiosk treatment methods and the attitudes of kiosk owners towards efforts to improve water quality. Chapter three filled these research gaps. It demonstrated that water quality from kiosks in downtown Cap-Haitian and surrounded districts is poor with high health-risk for households. The water does not meet standards for safe drinking water set by the WHO and DINEPA. This supports hypothesis *iii* of this dissertation.

Surveys of kiosks supported hypothesis *iv* of this dissertation, demonstrating that poor drinking water quality is caused by insufficient water treatment methods and irregular facilities maintenance. The *E. coli* and total coliforms level were high, indicating a health-risk associated with this unsafe drinking water with the potential for outbreaks of typhoid and other waterborne diseases. On the other hand, for-profit kiosks in Quartier Morin and Limonade supply drinking water with lower health risks, which could be due to the absence of sanitation concerns in these municipalities. Fortunately, there is some willingness to periodically pay for drinking water testing among kiosk owners in Cap-Haitian, Quartier Morin and Limonade municipalities. This is in accordance with descriptive analysis showing 55% of kiosk owners have been using powder to perform some drinking water testing for total dissolved solid at the kiosk level. Additionally, some kiosk owners are willing to pay for transportation services to take the water samples to the laboratory. These are some factors which the Lab manager can utilize to increase the water testing demand and make the laboratory sustainable.

5.2.3. Sensitivity to operating costs, user demand, and economic conditions

For-profit businesses and social institutions in Haiti that require fees to support operating costs have always faced economic challenges and struggled to achieve financial sustainability. The macroeconomic instability in Haiti, the low incomes of most of consumers, and the need to import major products prevent high transaction volumes. Drinking water testing is a new service in the Northern Corridor that will necessitate new practices among water vendors and adaptations for full efficiency. Additionally, water consumers' awareness of poor kiosk water quality, which could increase kiosk vendors' water testing demand, is uncertain. Thus, to ensure the sustainability of the drinking water laboratory over a five-year horizon of operation, it is critical to anticipate the cost of testing, client demand and willingness-to-pay, and the potential effects of broader economic changes (McLaughlin et al., 2008). There is a need to quantify the relative importance of the major factors that will affect the profitability of the laboratory to sustain its operation over time.

The fourth chapter of the dissertation addressed this gap and determined the conditions necessary for the sustainability of water testing services in the Northern Corridor. Daily testing demand, requests for microbiological testing per sample, and price-based incentives are the main factors that will determine profitability of the CHCL drinking water laboratory. The international chemical pricing index and Haitian inflation rates may also affect laboratory profitability, but to a lesser extent. While this supports hypothesis *iv* of this dissertation, factors other than inflation, which were not included in the hypotheses, were more influential. Sensitivity analysis indicated that when inflation is considered, an average of five samples received per day for routine microbiological and chlorine testing will allow the laboratory to be profitable under most scenarios. Thus, to ensure the cost-effectiveness of the operation, laboratory staff must initiate and follow a marketing plan that includes brochures, instructional leaflets, and radio announcements as relevant tools to communicate laboratory capabilities and procedures to customers with a particular focus on for-profit kiosk owners.

5.3. Limitations

The analyses in this dissertation have several limitations. First, in chapter two, only community-level factors such water bodies, travel time and socioeconomic conditions were considered. This chapter only investigated the presence of water bodies but did not determine the actual water sources used in these communities. It also did not consider wells, which are a major water source. Second, in chapter three, a minority of kiosk owners were willing to respond to survey questions. This resulted in a smaller sample size and could potentially bias the sample. Low response rates are a common issue with willingness to pay surveys. Finally, the financial sensitivity in chapter four assumes that the lab will operate under conditions without natural disasters or political instability. While this is a common assumption in this type of analysis, Haiti is vulnerable to hurricanes and earthquakes, and political disruptions have been common in recent years. Methods are needed for analyzing financial sustainability in systems that experience frequent disruptions.

5.4. Future research

This dissertation suggests several directions for future research. Chapter three demonstrated that unsafe kiosk water quality is mostly a problem in areas with poor sanitation. Future analysis should investigate the correlation between the distance of latrines, which are potential *E. coli* sources, to wells where kiosk owners' source raw water. Further, some of these areas experience frequent floods. Additional work should test kiosks repeatedly over time to determine the impacts of floods on water quality. The water quality analysis considered only for-profit kiosks. Plastic bag water has a high market share in Cap-Haitian; however, the water treatment methods are unknown. Future work should consider the safety of plastic bag water.

Finally, the financial sensitivity analysis (chapter 4) should be extended to consider how the factors identified through kiosk owner surveys (chapter 3), such as testing mandates, would affect the sustainability of the laboratory.

5.5. Regulations and enforcement

One of the main conclusions of this dissertation is that mandatory water kiosk surveillance and enforcement by the government would be one of the most effective strategies to increase water testing and guarantee safe drinking water in Haiti. I propose the following to the Haitian government to guarantee safe drinking water to household members:

- The public health directors in both North and Northeast departments shall regulate the drinking water sector in the Northern Corridor and enforce all rules regarding drinking water and regulations promulgated and adopted pursuant to safe drinking water for all inhabitants coming from any enterprises.

- The primary drinking water regulations in the Northern Corridor shall apply to each kiosk or enterprise supplying drinking water in the region with no exception and the regulations must include, but not be limited to, the:

    - ✓ Inspection of treatment facilities, storage facilities, and distribution facilities.
    - ✓ Oversight of the operation methods and appraisal of the owner’s motivation or operator’s abilities to properly operate the facilities.
    - ✓ Surveillance of water distribution to ensure that secondary water vendors/distributors own adequate infrastructure to sell safe drinking water.
    - ✓ Regular training of distributors, operators, and kiosk owners regarding the new policies/regulations.

    - ✓ Requirement of regular drinking water testing based on filter lifetime.
    - ✓ Establishment of maintenance plans for all facilities.
    - ✓ Emphasis in slums and flooded zones with/without sanitation concerns.

- Both directors shall initiate procedures for the enforcement of the rules and regulations promulgated and adopted with active inspectors, including, but not necessarily limited to, weekly monitoring based upon well-established inspection procedures.

- Both directors shall keep such records and make such reports with respect to the integrity of all enterprises to avoid disloyal competition.

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