Heliyon 10 (2024) e38063

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Pricing drinking water testing in northern Haiti: Financial sensitivity to operating costs, user demand, and economic conditions

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ARTICLE INFO

Keywords:
Drinking water laboratory
Financial sustainability
International development
Haiti
Internal rate of return
Financial sensitivity

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. 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 on profitability. Finally, international and Haitian inflation cause some 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.

1. Introduction

Unsafe drinking water and poor sanitation and hygiene contribute to an estimated 4 billion cases of diarrheal disease annually, causing 1.8 million global deaths, mostly among young children [1]. Over the past few decades in Haiti, inhabitants have suffered from waterborne diseases due to chemical and microbiological contamination of drinking water [2–5]. Haiti experienced a cholera outbreak in 2010, which affected all ten provinces in Haiti and spread to the neighboring Dominican Republic [6].

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https://doi.org/10.1016/j.heliyon.2024.e38063
Received 6 November 2023; Received in revised form 7 August 2024; Accepted 17 September 2024
Available online 18 September 2024

After the cholera outbreak, small-scale private-sector water vendors, known as kiosks, became increasingly important. These neighborhood units typically operate as franchises of provider companies. Kiosks often use reverse osmosis (RO) membrane filtration and offer treated water for sale in one- or five-gallon units [7]. 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 [8]. 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 [9,10]. The cost of treating a case of typhoid in Haiti is typically US $300 [10].

A good practice for kiosk owners is to regularly test drinking water to ensure its safety. While regulations can mandate testing [11], it is unlikely that establishment and enforcement of drinking water regulations will occur in Haiti, so market-based solutions are required. The reliance of Haitians on for-profit kiosks creates a nexus between economics and drinking water. 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 [12,13]. Testing should be done by reliable laboratories that provide competent interpretation by trained personnel [14].

Most actions to address these drinking water quality concerns have occurred in central and western Haiti, with few interventions in the northern regions despite the large and vulnerable populations there. With a population of 253,617, the annual total expenditures for typhoid treatment during an outbreak in the northern city of Cap-Haitian could be up to US $38.8 million [15,16]. Additionally, hazardous chemicals are present in the region. In Trou du Nord and Caracol, communes 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) [5,17].

1.1. *Need for testing services*

Haiti does not have a water testing laboratory in the Northern Corridor. The Spanish government development agency is working with the Regional Office of Drinking Water and Sanitation/Office Régional de l'Eau Potable et de l'Assainissement (OREPA) to establish laboratories in central and southern Haiti, but neither is currently operational. Two water testing laboratories operate in Port au Prince [18]. However, conditions in Haiti make it difficult to utilize a laboratory in another city [19], and testing fees are expensive [20]. Government agencies have inadequate infrastructure and often lack funds to maintain reagents and instrumentation [21]. The development of water testing services can contribute to better health and wellbeing for the broader population [9].

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 Henri Christophe Campus of the State University of Haiti (CHCL-UEH), 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. These municipalities do not have treated tap water. The laboratory service is intended to monitor drinking water sources to ensure safety and enhance consumer confidence [22]. The laboratory also seeks to build the capacity of local drinking water technicians. This location was selected due to the lack of existing testing services, the vulnerability of Haiti to waterborne diseases, and the long-term relationship among the project partners. However, the results of the analyses in this manuscript can inform the establishment of laboratories to provide commercial services in other developing countries, particularly those that rely heavily on drinking water purchased from private vendors.

1.2. *Projecting financial viability*

In the Northern Corridor, water providers have never participated in drinking water testing, which could impede lab profitability [21]. To ensure economic viability of the drinking water laboratory, it is critical to anticipate the cost of testing, client demand and willingness-to-pay, and the potential effects of broader macroeconomic factors [1]. Few consumers and business owners seem fully aware of the relevance of drinking water testing in the Northern Corridor. Thus, a persuasive marketing strategy could increase the use of testing services and enhance the financial viability of the laboratory [23]. Further, sudden currency fluctuations and inflation may affect demand for tests and laboratory cost structures [24].

Prior studies have evaluated improving drinking water quality in developing nations. For example, Boukhari and de Miras show the economic challenges of achieving financial sustainability for water sanitation and supply firms in Algeria [25]. Other studies have focused on the potential to establish water testing facilities. Delaire et al. [26] use data from water monitoring facilities across fifteen sub-Saharan African nations to analyze microbiological water quality testing costs. The authors find that annual facility costs differ immensely across nations, which is in part dependent on the different sizes of the populations served by the facilities.

Similarly, Crocker and Bartram compare the costs of water monitoring in seven countries throughout the world [27]. They conclude that sample transportation and labor represent three-quarters of the marginal costs, showing the limitations of fixed-location laboratories. In Haiti specifically, two studies have evaluated the efficacy of low-cost methods to test drinking water quality [3] and treat drinking water in households [28]. 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 a developing nation. This is especially important in Haiti, a country that has faced grave waterborne illness outbreaks in recent years.

In Haiti, anticipating cost increases is important for ensuring financial viability due to the dependence on imported reagents and supplies [29]. The internal rate of return (IRR) was used to assess if the laboratory is profitable relative to costs and benefits by using capital budgeting to create accountability [30]. 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 [31]. IRR is one indicator of the usefulness of an investment and has been extensively used for the appraisal of public investment decisions [32]. Other risk-analysis methods for the identification of critical threats to financial viability could suggest necessary management decisions [33].

The rationale of this paper is to analyze the financial operations of the CHCL-UEH laboratory to identify strategies to ensure sustainable operations. This is needed due to the lack of previous studies evaluating the economic viability of laboratory operations in a developing country and the challenging and unstable economic environment in Haiti. This paper has the following objectives.

- Analyze the profitability of the drinking water laboratory at CHCL-UEH over a five-year period.
- Analyze the uncertainty in profitability by considering different increments of daily sample demand from different potential clients, the combination of tests performed on each sample, and different test pricing schemes.
- Assess the sensitivity of profitability to an international chemical pricing index and Haitian inflation.
- Based on these analyses, suggest strategies that laboratory management might undertake to ensure profitability.

The strategies identified by this study will be implemented in the CHCL-UEH laboratory. These strategies may be transferrable to other developing countries, particularly those with high inflation and unstable governance. Further, the analysis methods provide a framework for economic evaluation for other projects seeking to develop laboratory capacity in developing countries.

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 water quality parameters. 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 inputs used on each test, and FC are the fixed costs of production.

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 [34]. Specifically, the *NPV* is defined as:

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

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 $NPV(I, R_1, \ldots, R_T, \rho, t) > 0$. The cash flow ($R_t$) is equal to the annual net returns to the laboratory as described in equation (1), by subtracting the laboratory's revenues from its costs. The laboratory revenues come from charges for testing sales, whereas costs include chemicals, technician labor, depreciation, maintenance and repairs, interest expenses, and other supplies.

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 outflows at the end of the project, including the investment cost [35]. In other words, the *IRR* is the minimum rate of return that the project must obtain to be worth undertaking. Formally, the *IRR* is defined as the value r such that

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

From equations (2) and (3), the project is profitable if $r > \rho$, thus the *IRR* and *NPV* both provide equivalent evaluation criteria [34]. 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*) [36].

2.1. 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 [37]. This is because both the *NPV* and *IRR*, hence profitability, are affected by several exogenous factors whose values are not known with certainty [38]. 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*) [39].

We center on the *IRR*, as that is the measure of focus in our analysis. We define *IRR* as a function of exogenous parameters in equation (4), such that

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

is a differentiable function in $X = (x_1, \ldots, x_n)$, a matrix of input parameters [34]. The following *DIM* is defined by equation (5) as

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

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 [40]. 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 [39]. 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 [41].

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 [42]. 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 [43].

The motivation may be effective while providing some incentives [44] that could increase kiosks owners' ability to order water testing services by lowering the unit aspect price [44,45]. Furthermore, political crises that are recurrent in Haiti are a crucial source of inflation that could affect the price of laboratory consumables [46].

3. Methodology

3.1. Study area and target population

The CHCL-UEH laboratory in Limonade, near the major city of Cap-Haitian, is intended to serve the Northern Corridor departments of Haiti. 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 [19]. Additionally, Ouanaminthe and Fort Liberty are economic hubs of the Northern Corridor in which water providers could transport samples by private vehicle. The population of these eight municipalities is 357,000.

Cap-Haitian has struggled to develop sufficient water services [47]. Although investments in the sector have increased significantly in recent years, the sustainability of drinking water services remains fragile and uncertain [47]. Water sources are not 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 [47]. 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).

3.2. Testing plan

The recommended chemical test parameters for water sources in Haiti that can be completed by the CHCL-UEH lab are arsenic, fluoride, lead, manganese, nitrate, and nitrite. 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-UEH 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 h), and frequent (weekly to daily) testing is a reliable way to ensure proper water treatment.

3.3. Testing methods

Testing is performed in the soils and water testing laboratory located on the CHCL campus. It occupies two rooms, each about 50 m^2 in area. One room is primarily used for soils testing, but includes some shared equipment utilized by the drinking water lab (drying oven, fume hood). A second room is dedicated to water testing with a 24-h power supply with battery back-up, climate control, and refrigeration. Major equipment in the water testing laboratory includes a BioClave 16 autoclave (Ward's Science, Rochester, NY) and low-temperature incubator (VWR, Radnor, PA). Samples are collected and delivered to the lab by clients. Laboratory personnel offer sterile sampling bags and instruction sheets describing standard drinking water sampling procedure.

Testing methods were selected for the laboratory that comply with US ASTM and EPA standards to the extent allowed by available equipment, supplies, and infrastructure. Conductivity and pH are measured with LabQuest sensors (Vernier Science Education, Beaverton, OR) following EPA Methods 150.3 and 120.1, respectively. TDS is measured by evaporation following EPA Method 160.1. Turbidity is measured with a TL2310 Turbidimeter (Hach, Loveland, CO). Free and total chlorine are measured with a DC1500 Colorimeter (LaMotte, Chestertown, MD) using the N,N-diethyl-p-phenylenediamine (DPD) method (EPA Method 330.5). A screening test for arsenic is performed using low range test strips (Hach, Loveland, CO), which are compliant with the EPA Arsenic Rule. Fluoride is measured with an Orion ion-selective electrode (Thermo Fisher, Waltham, MA) following EPA method 9214. A screening test for lead is performed with a test kit (LaMotte, Chestertown, MD). Nitrate is measured with a LabQuest electrode sensor (Vernier Science Education, Beaverton, OR) following EPA Method 9210A. Nitrite is measured using a NI-12 Test Kit (Hach, Loveland, CO), which uses the cadmium reduction colorimetry method. Manganese is measured using a MN-5 Test Kit (Hach, Loveland, CO), which uses the cold periodate colorimetry method. Total coliforms and *E. coli* are measured by membrane filtration followed by culturing and enumeration on Difco MI Agar (BD Biosciences, Franklin Lakes, NJ). This procedure follows EPA Method 1604. The laboratory follows all quality control and quality assurance procedures recommended in the EPA methods, test kit instructions, and equipment user manuals to ensure reliable results.

While the laboratory seeks to provide consistent service, working in Haiti brings challenges and limitations. Some expendable supplies must be obtained from either the United States or the Dominican Republic, which may be impossible when political instability disrupts the operation of border crossings or shipping locations. Further, there is frequent turnover among laboratory staff as trained technicians frequently pursue education or employment opportunities abroad due to the uncertainty surrounding Haiti's future. CHCL-UEH leadership and collaborators from Auburn University seek to be a stabilizing force by supporting the acquisition of supplies and holding training courses for laboratory staff.

3.4. *Empirical application: CHCL-UEH laboratory profitability*

3.4.1. *Projected water testing demand*

The potential water testing demand was estimated based on a 2020 water assessment for Cap-Haitian conducted by USAID [48]. 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. It was assumed that the fraction of drinking water samples from each type of domestic water provider would be proportional to the fraction of households using that water source. Each relevant NGO, large school or university, and industrial operation in the region was identified and it was assumed that each would provide one sample per month. Based on the results of this analysis, the expected number of samples 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, or around five tests per day. Both training and testing services will be part of the laboratory's mission. We assume one laboratory technician training session per month generating $2000 in income.

3.4.2. *Operation revenues*

To start, prices were set in US dollars 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. These prices are based on the prices charged for the same test by the DINEPA drinking water testing lab in Port au Prince as of October 2019. The DINEPA lab was used as an example of prices that would be competitive on the local market due to the absence of other drinking water testing laboratories in northern Haiti. If all 11 parameters are tested on each of the 96 samples, the revenue for drinking water testing is estimated to be $5827 per month. To compensate for any cost increase, the actual test fees may be set higher than these initial fees.

3.4.3. *Operation expenses*

Full details for one-year operation costs are given in Table 1, and the annual costs by year are shown in Table 3. Determining

Table 1
First-year operation costs for the CHCL-UEH drinking water laboratory in U.S. dollars.

Items	Months	Cost per Month	One Time Costs	Total Cost
Advertising/Marketing	3	$500	$500	$2000
Technician Salaries	12	$800	$0	$9600
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**

operation costs is critical to ensure enough cash is available to begin laboratory operations within the budgeted time frame and within the cost budget. Operation costs typically fall within two categories: monthly and one-time. Monthly costs occur throughout the existence of the laboratory, and one-time costs are incurred once during the startup period. Net returns are calculated as the total revenues minus total expenses. To obtain cash flow, we deduct the depreciation expense from the net returns, as depreciation is treated as not dispersed.

3.4.4. Local inflation and international chemical index

International and Haitian inflation will affect lab costs and profitability through *IRR*. International chemical index data from ChemIndex was used, which measures average annual changes in chemical prices [49]. The average annual international chemical index was 6 % from 1985 to 2020 meaning that the laboratory is likely to face some inflation in the cost of laboratory supplies. Haitian inflation data were taken from the Intitut Haitien de Statistique et d'Informatique/Haitian Institute of Statistics and Informatics (IHSI) [50]. The inflation rate provided by IHSI from 1986 to 2020 is on average 12 % annually (Table 2). The analysis assumed that CHCL-UEH will annually supply the laboratory with chemicals and purchase local goods and services.

In the case of rising prices, the laboratory manager would likely pass those costs through to the consumer while being cautious to avoid significant decreases to the demand level. Because the cost increase would be detrimental to the profitability of the drinking water laboratory, the manager may need to absorb the cost increases without significantly increasing the pricing of services. Accordingly, the drinking water lab must respond by better managing incurred costs and seek methods to reduce them. Due to the uncertainty of pricing on both the input and output side, we further evaluate effects of changing prices on laboratory economic viability.

3.5. Sensitivity analysis

We examined the following dimensions of variability in water testing services, as each influences the profitability of the lab and/or guides aspects of laboratory operation.

- *Number of samples received daily or monthly*: The number of samples received by the laboratory will determine the volume of revenue generated. It depends on the extent of marketing efforts by the laboratory staff. Thus, understanding the number of samples that must be received to ensure sustainable operation will provide a target for these efforts.
- *Types of tests ordered for each sample*: The price of testing for each sample, and thus the revenue generated, depends on which tests the client requests. This will depend on the types of clients served and which water sources they are using.
- *Fees charged per test*: The pricing strategy described in section 3.4.2 is only a starting point that is based on fees charged by the DINEPA lab in Port au Prince. Due to the different setting and institutional structure of the CHCL-UEH lab, higher fees may be required to ensure sustainability. Alternatively, if sustainability can be achieved with lower testing fees, this would help to generate higher testing volumes.
- *Local and international inflation*: The Haitian economy has been characterized by high inflation in recent years. This will affect laboratory profitability by controlling the operation costs of the lab related to labor, utilities, and supplies that can be purchased locally. Many expendable laboratory supplies and replacements for durable supplies and equipment need to be imported from abroad. Therefore, international inflation is also relevant to laboratory profitability.

The focal outcome is the *IRR*, computed from the net cash flow over five years. 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. USAID normally employs a discount rate of 12 % as a decision standard. The sensitivity analysis examines test demand variations on the profitability of the drinking water lab as a business developed at CHCL-UEH. Analyses were performed in Microsoft Excel 16.0 and all values reported are in US dollars.

Table 2
Distribution of the frequency at which the annual local inflation rate for Haiti and the international inflation rate for laboratory supplies given by the chemical international index fell into specified ranges.

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		

Table 3
Five-Year Cash-Flow Plan: Net Present Value (NPV) and Internal Rate of Return (IRR) for the laboratory calculated from revenues, expenses, and returns.

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
REVENUES						
Grants and Equity	($63,746)					
Gross Revenues		$55,701	$74,040	$74,040	$74,040	$74,040
Total Initial Investment	($63,746)					
Total Revenues		**$55,701**	**$74,040**	**$74,040**	**$74,040**	**$74,040**
EXPENSES						
Chemicals		$7270	$7634	$8016	$8416	$8837
Technician Salaries		$9600	$9600	$9600	$9600	$9600
Travel		$2880	$2880	$2880	$2880	$2880
Depreciation costs		$7281	$7281	$7281	$7281	$7281
Maintenance & Repairs			$1722	$1722	$4486	$4486
Interest Expense		$3187	$3187	$3187	$3187	$3187
Other Costs		$8900	$8900	$8900	$8900	$8900
Total Expenses		**$39,118**	**$39,481**	**$39,863**	**$40,264**	**$40,685**
RETURNS						
Net returns	($63,746)	$16,583	$34,558	$34,177	$33,776	$33,355
Cash flow (net returns – depreciation)	($63,746)	$23,864	$41,839	$41,457	$41,057	$40,636
Present Value of Cash Flow	($63,746)	$21,307	$33,354	$29,509	$26,092	$23,058
NPV: $69,574			**Financial IRR: 47 %**			

Note: 12 % discount rate used to calculate net present value.

4. Results

4.1. Depreciation costs

The drinking water lab was equipped with an autoclave, incubator, refrigerator, and a solar power system to supply 24-h electricity. In total, 53 small equipment items, 11 large equipment items, and 139 items for power supply were purchased. The total cost of equipment was $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 [51]. It is assumed that maintenance and repairs to maintain equipment will be spent annually as described in Table 3.

4.2. Projected cash flows

For the first year of operation, we predict $5,770 in gross revenues each month with full testing and $5,740 in 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 provided to all clients. This marketing strategy encourages new clients to use the lab and was used successfully during the establishment of a soil testing laboratory at CHCL-UEH (O. Jean, Dean, personal communication, July 2021). The total revenues are $55,701 and the net returns total $16,583 for the first year. However, full pricing will be applied for the second year providing a net return of $34,558 (Table 3).

4.3. Assessment of economic viability

The full results (Table 3) demonstrate that the cash flows 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 five years, the drinking water testing lab will generate a positive NPV of $69,574. The IRR of 47 % is greater than the 12 % discounting rate, which suggests the project is worth undertaking. Assuming no refund for capital or interest and the positive NPV values, we anticipate long term sustainability for the drinking water testing lab at CHCL-UEH.

4.4. Sensitivity analysis

4.4.1. IRR under various risks

First, we consider the scenario in which all clients request a standard testing plan with a full suite of 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 −4%. However, if microbiological testing is also performed, as recommended by the WHO, the *IRR* will be 47 %, greater than the USAID requirement of 12 %. 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 further increase 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*. 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 (Fig. 1). Based on preliminary market analysis, we expect that three or four daily samples is the most realistic, providing an *IRR* of 32 % and 115 %, respectively. Without microbial testing, six daily samples would be required to exceed the USAID 12 % IRR, demonstrating the importance of microbial testing for laboratory viability.

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. Fig. 2 shows that 20 monthly samples from kiosks with only chlorine testing will provide an *IRR* of −13 % whereas 20 monthly samples with chlorine and microbiological testing will provide an *IRR* of 36 %. The laboratory must receive at least 12 samples per month from kiosk owners to maintain a positive NPV. However, if clients routinely request one additional chemical test, such as the nitrate testing recommended for sources near agricultural areas, then the laboratory could be profitable even without for-profit kiosk owners as clients (Fig. 2), demonstrating an alternate strategy to achieve profitability.

4.4.2. Pricing practices

We analyzed how pricing strategies will affect sustainability. The change in microbiological unit price has low risk on the projected *IRR*. The projected *IRR* will be 20 % and 38 % for a pricing of $9.50 based on three and four samples per day, respectively (Table 4). A pricing level of $10.50 provides an *IRR* or 23 % and 41 % for three and four samples per day, respectively. While the microbial testing fees have some effect on profitability, it is not as significant as the effect of clients not ordering microbiological tests or lower sample demand. Therefore, reducing microbial testing prices to increase demand could be among the best strategies to make the lab financially viable.

4.4.3. Inflation

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 (Table 5). For Haitian inflation up to 35 %, four samples per day will keep the projected *IRR* greater than 12 %. At a demand of five samples per day, the projected IRR will exceed 12 %, even with Haitian inflation at 40 %. Local inflation, which can be up to 46 % in Haiti, would 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.

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. Though inflation poses less risk than the other factors, it remains challenging for a laboratory in a location like Haiti. The *IRR* volatility related to Haitian inflation is similar to the price volatility and the market overreaction during the political crisis triggered by the Taiwanese election of 2004 [52]. Companies with better corporate governance or performance experienced less price volatility and less increase in volatility during the crisis. Therefore, the laboratory should establish a clear and transparent management and governance plan.

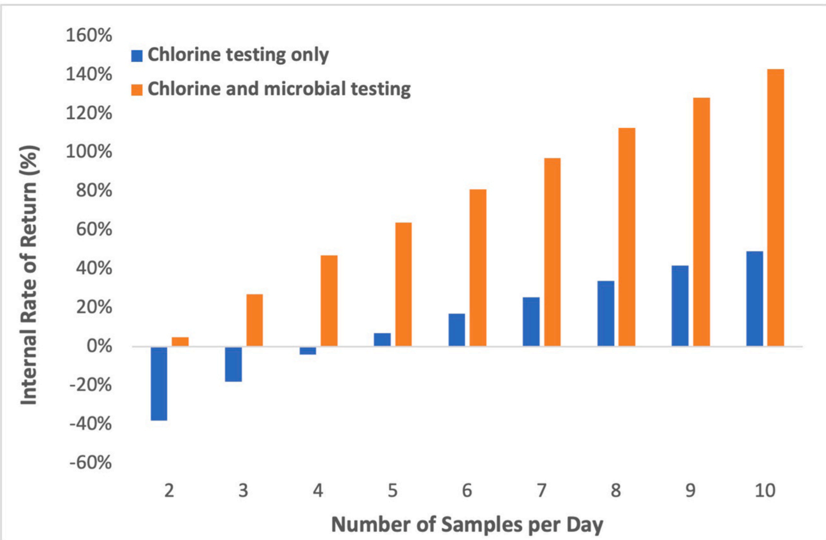

Fig. 1. Sensitivity of laboratory IRR to the number of samples received per day. Blue bars indicate a scenario in which only residual chlorine testing is performed on the samples and orange bars indicate a scenario in which microbiological testing is also performed.

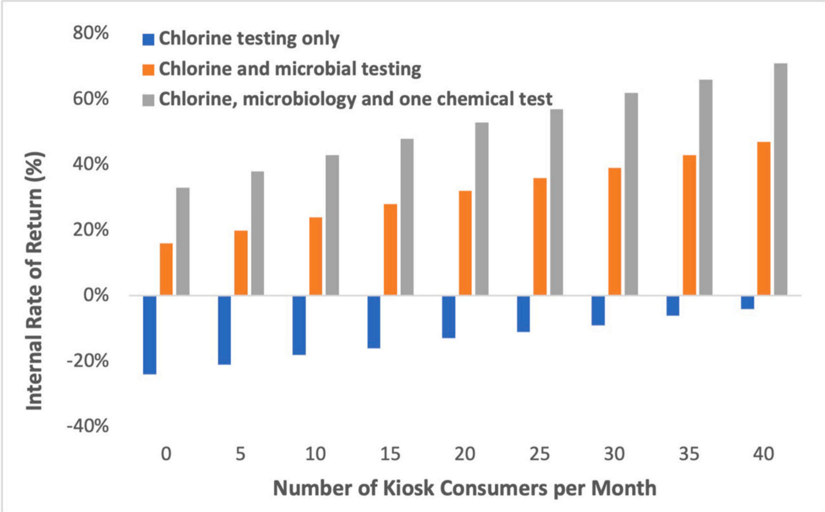

Fig. 2. Sensitivity of IRR to monthly testing demand from kiosks depending on which tests are requested by the client.

Table 4
Sensitivity of IRR (%) to a range of microbiological testing fees and daily sample demand.

Microbiological Testing Fees (USD)	Number of Samples Processed per Day					
	3	4	5	6	7	8
$6.00	8 %	24 %	38 %	51 %	64 %	75 %
$6.50	10 %	26 %	40 %	54 %	66 %	79 %
$7.00	12 %	28 %	43 %	56 %	69 %	82 %
$7.50	13 %	30 %	45 %	59 %	72 %	85 %
$8.00	15 %	32 %	47 %	61 %	75 %	88 %
$8.50	17 %	34 %	49 %	64 %	78 %	91 %
$9.00	18 %	36 %	52 %	67 %	81 %	94 %
$9.50	20 %	38 %	54 %	69 %	84 %	98 %
$10.00	21 %	40 %	56 %	71 %	86 %	101 %
$10.50	23 %	41 %	58 %	74 %	89 %	104 %
$11.00	25 %	43 %	60 %	76 %	92 %	107 %
$11.50	26 %	45 %	62 %	79 %	95 %	110 %
$12.00	28 %	47 %	64 %	81 %	97 %	113 %

Table 5
Sensitivity of IRR (%) to Haitian inflation and the International Chemical Price Index based on sample demand.

		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
Haitian Inflation (%)	**5**	25	24	23	22	20	44	44	43	42	41	62	61	61	60	59
	10	22	21	20	19	17	42	41	40	39	38	60	59	58	58	57
	15	19	18	17	16	14	39	39	38	37	36	57	57	56	55	55
	20	17	15	14	13	11	37	36	35	34	33	55	54	54	53	52
	25	14	13	11	10	8	34	34	33	32	31	53	52	51	51	50
	30	11	10	8	7	5	32	31	30	29	28	50	50	49	48	47
	35	8	6	5	3	1	29	28	28	26	25	48	47	47	46	45
	40	5	3	2	0	−2	27	26	25	24	23	46	45	44	43	43

Our analysis demonstrated a low potential impact of international inflation on the laboratory's economic viability. However, the prices of imported commodities or manufactured products from China, which the lab is heavily dependent on, are strongly connected with global commodity prices [53]. Further, the profitability of the laboratory is highly elastic to the demand for water testing, so a price incentive strategy may increase profitability. This result is consistent with wind electricity in China, where achieving effective outcomes required price incentives [54]. At some point, the laboratory will need to increase fees to respond to inflation. The laboratory management team will work to build long-term relationships with clients, particularly kiosk owners, which has been shown to increase customer retention following price increases [55]. Additionally, they will engage in transparent communication with clients about the need for fee increases to reduce the perception of unfairness [56].

Because for-profit kiosks are the largest potential client group, emphasis should focus on maximizing the number of kiosks that request testing to increase demand [57]. However, increased advertising does not always enhance the value of a business [58]. Therefore, the drinking water laboratory manager must develop smart marketing to ensure consistent demand to keep the laboratory profitable. Better understanding of the factors that drive demand for water testing in Haiti will be crucial. In addition, 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 [59]. Laboratory staff should attend 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.

This paper adds to existing literature on the economics of drinking water sanitation in developing countries at a firm-level scale. While prior work has not evaluated the financial viability of water-testing laboratories, several past studies evaluate the costs of water monitoring at the country level in sub-Saharan Africa and southeast Asia. For example, Crocker and Bartram [27] show that the marginal cost per water test across seven countries averaged around $7 per sample, but with substantial variation across countries and by facility size. Testing costs at the laboratory in Limonade would equal $9.50 per microbial test in the default scenario. However, given that the IRR was not sensitive to microbial testing fees, decreasing the microbial testing price could increase testing demand thus increasing profitability.

A greater understanding of what price points are feasible for water-testing laboratory customers will be necessary to better understand the impact of the higher estimated testing cost. At a country-level scale, Delaire et al. [26] estimate that it would cost $16 million per year to monitor microbial quality of all sub-Saharan African improved water sources. In Rwanda – a country with a similar population to Haiti – the cost is just $290,000 per year. In comparison, the estimated annual expenditure to treat a waterborne disease outbreak is about $38 million for the Cap-Haitian population. The estimated investment costs for establishing a drinking water laboratory are $63,746 with $40,000 in operating expenses annually, which indicates that there are substantial economic benefits to successfully increasing water testing in the Northern Corridor of Haiti.

One limitation of this study is the lack of data on demand for water testing in Haiti. Future work will analyze kiosk owner willingness-to-pay for water testing to further enhance estimates of kiosk owner demand. Another limitation is that this analysis considers the economics of maintaining a laboratory but does not consider public benefits of water testing such as improved health and wellbeing. Future work should consider the health benefits in conducting widescale cost-benefit analysis of water testing to determine whether scaling up would make sense. Lastly, our analysis uses sensitivity analysis to assess the viability of the laboratory under varying environments due to the lack of data on market demand, testing fees, and input prices. Future studies should conduct simulations of factors affecting the laboratory financial analysis to obtain stochastic estimates of economic viability and better understand the likelihood of financial viability.

6. Conclusions

Daily testing demand, requests for microbiological testing per sample, and providing price-based incentives are the main factors that determine profitability of the CHCL-UEH drinking water laboratory. Inflation rates also affect laboratory profitability 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 cost-effectiveness of the operation, laboratory staff must initiate and follow a marketing plan 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.

Data availability statement

All data used in the analyses presented are available in the text and tables of this manuscript.

CRediT authorship contribution statement

Lonege Ogisma: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Frances C. O'Donnell:** Writing – review & editing, Visualization, Supervision, Project administration, Methodology, Funding acquisition, Formal analysis. **Wendiam Sawadgo:** Writing – review & editing, Supervision, Formal analysis. **Joseph J. Molnar:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Gobena Huluka:** Writing – review & editing, Methodology, Formal analysis. **Esther Laguerre:** Visualization, Formal analysis, Data curation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Frances O'Donnell reports financial support was provided by DAI. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors acknowledge the following people for their advice, assistance, data, and other valuable contributions to this study: Jean-Fritz Saint Preux, Graduate Student from Auburn University and Samuel Mondestin from USAID-WATSAN-project. This work was funded by the United States Agency for International Development (USAID) DAI Prime Contract OAA-I-14-00049/720521.

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