

Container-based sanitation in urban Haiti: how can it improve human rights as a component of citywide inclusive sanitation?

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ABSTRACT

Health, sanitation, and livelihoods are interrelated human rights and essential components of community wellbeing. Despite the United Nations recognizing the human right to sanitation, one-third of the world's population lack access to improved sanitation. Furthermore, in many low- and middle-income countries, urban latrines are excavated manually without physical or regulatory protections. Container-based sanitation (CBS) has promise as a component of Citywide Inclusive Sanitation (CWIS) in densely populated, low-resource environments. Before investing in CBS, however, governments and funders require evidence of user acceptance, public demand, and labor aspects of service delivery. To provide this evidence base, we completed 633 interviews with active and former users of EkoLakay, a CBS service in Cap Haïtien, Haiti, creating a profile of the user base and their motivations for subscribing. We also compiled and analyzed secondary data to determine the impacts of widespread CBS expansion in northern Haiti. Results reveal that CBS presently serves a geographical subset of Haiti's most resource-insecure residents, and that CBS significantly reduces handling of untreated excreta in Haiti's Nord Department, while doubling livelihood opportunities through safe and dignified jobs. Given its cost-effectiveness, this provides an opportunity to achieve widespread sanitation coverage by integrating and cross-subsidizing CBS within a CWIS strategy.

Key words: Citywide Inclusive Sanitation, container-based sanitation, human rights, safely managed sanitation, sanitation systems, SDG 6

HIGHLIGHTS

- First systematic study of CBS's impact on vulnerable households.
- Haiti's sanitation system leaves 19% of urban households without improved sanitation access.
- Haitian CBS users had above-average rates of open defecation and limited sanitation pre-CBS.
- CBS could help urban sanitation systems in LMICs achieve SDG 6.
- CBS can replace 1 M hours of unsafe excreta-handling labor with 500+ safer jobs in northern Haiti.

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GRAPHICAL ABSTRACT



INTRODUCTION

Sanitation systems and human rights in the global South

Access to safe sanitation is an essential underpinning of human rights, recognized by the [United Nations \(UN\) Committee on Economic Social & Cultural Rights \(2010\)](#) and the [UN General Assembly \(2016\)](#). However, as of 2020 only a little over half of the global population has access to safely managed sanitation ([WHO 2021](#)). This includes six hundred million people in urban areas, where the negative health implications of open defecation are intensified by population density and lack of environmental ‘sinks’ for excreta. UN Sustainable Development Goal (SDG) 6.2 challenges the world to ‘achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations’ by 2030 ([UN General Assembly 2015](#)). At the present pace of progress, we will fall far short of this target; the number of households without sanitation is increasing, and the gap between rich and poor is exacerbating, as urbanization outpaces the development of public services ([UNICEF 2019](#)). While many technologies meet the definition of improved sanitation, they cannot achieve the conditions described in SDG 6.2 without connections to processes for safe excreta management. Such is the case in many urban environments in fragile contexts ([WHO 2021](#)). Sewers that discharge excreta into the environment without treatment threaten the rights to health and safe drinking water. Latrines that must be manually excavated undermine the right to safe working conditions protected by the Universal Declaration of Human Rights ([UN 1948](#)). Where the proliferation of latrines creates a class of citizens who are stigmatized and subject to public abuse ([Neiburg & Nicaise 2011](#)), it violates the right to be free from inhuman or degrading treatment, ‘laying the groundwork for violations of human rights’ ([de Albuquerque 2012](#)).

Some scholars suggest that the global sanitation deficiency is partly a product of fixation on centralized, water-based technologies ([Gambrill *et al.* 2020](#)). Homogeneous systems certainly benefit from physical and organizational simplicity, making them attractive to public service coordinators. Centralized sewers, however, are inappropriate or unaffordable in many contexts, leaving them unable to meet SDG 6.2 alone ([Andersson *et al.* 2017](#)).

In recent years, the emerging Citywide Inclusive Sanitation (CWIS) framework has begun to guide the pursuit of equitable and sustainable urban sanitation access ([Schrecongost *et al.* 2020](#)). The CWIS framework views sanitation provision from a system-wide approach, recognizing the value of integrating varied technologies, service

models, and economic strategies to achieve universal sanitation coverage. Rather than focusing on specific technologies, CWIS framework measures success by access outcomes, considering the full sanitation service chain.

Container-based sanitation (CBS) may be an important tool within a CWIS portfolio; CBS, recognized by the World Health Organization (WHO) as a form of safely managed sanitation (WHO/UNICEF 2017) is a non-sewered sanitation strategy through which excreta is captured in sealable containers, and transported to facilities for treatment. CBS has low life-cycle costs (EY 2020; Sainati *et al.* 2020; Delaire *et al.* 2021), provides immediate sanitation coverage in locations without preexisting infrastructure, operates without water, and is resilient to environmental disruption (Russel *et al.* 2019). Where a CBS service is available, households can transition directly to private improved sanitation from any step on the sanitation ladder,¹ without substantial upfront investment in infrastructure. In flood-prone environments, CBS provides further advantages over pit latrines; the technology allows excreta to be stored above-ground and sealed against environmental release. In areas vulnerable to flooding, latrines (the most affordable traditional sanitation technology) are not capable of maintaining a safe barrier between a community and their excreta. A single flooding event can spread suspended excreta from latrines across the surrounding environment. After floodwaters have receded, pathogens in fecal solids that remain on the earth's surface can continue to pose a threat to human health for up to a year (Carr 2001). In addition, the portable nature of CBS technology enables it to provide sanitation coverage even where land tenure is disputed or unclear (such communities are home to the most vulnerable households). Finally, CBS separates both user and processor from direct contact with excreta (SOIL 2019), unlike commonly practiced manual latrine excavation (World Bank 2019).

Thus, expanding CBS as a component of municipal sanitation portfolios has the potential to alleviate the human rights crisis associated with manual excavation, in addition to meeting SDG 6.2. Before funders and public entities will confidently invest in CBS as a component of citywide sanitation delivery, however, they require real-world research for evidence-based decision making. Previous research has explored willingness to pay for CBS (Russel *et al.* 2015), practicalities of scaling CBS services, and cost-effectiveness of CBS (Tilmans *et al.* 2015; Sklar & Faustin 2017; EY 2020; Delaire *et al.* 2021). There remains a need for research into user acceptance, public demand, and labor aspects of service delivery.

In this study, we approach the challenges and opportunities of an equitable sanitation future by considering the role of CBS in the context of a complex system of interrelated economic, social, ecological, and technical subsystems (Clayton & Radcliffe 1996). For example, implementing innovations to the sanitation system, such as CBS, face many barriers which require new approaches to strategic planning (Spuhler & Lüthi 2020). However, the investment in financial and human capital to overcome these barriers is needed because 100% public sanitation coverage is likely unachievable without incorporating innovative sanitation solutions like CBS that can be implemented in areas with limited infrastructure or disputed lands. Such factors and their interactions are also explored by Hyun *et al.* (2019), in their Augmented Sanitation Service Chain framework. The authors define a sanitation system as more than its physical components; it is the full range of public and private actors engaged in sanitation provision, as well as the various practices, technologies, transactions, regulatory conditions, and social values driving local excreta flows. Through this lens, we see that the flow of excreta is accompanied by flows of power and capital, which can exacerbate inequalities or contribute to safe livelihoods. The technological aspects of excreta collection, conveyance, and treatment interrelate with human rights, dignity, health, and social wellbeing.

CWIS and the Augmented Sanitation Service Chain approach community sanitation from a system-wide perspective. Both approaches recognize the relevance of interacting systems at varying scales, to the efficacy of public sanitation endeavors. Applying these frameworks to low- and middle-income countries (LMICs), we can see that the novel characteristics of CBS may strengthen urban sanitation systems, improving their ability to yield equitable sanitation, health, and dignity outcomes. This research sets out to evaluate the potential system benefits of expanding the role of CBS in the urban sanitation system of an LMIC. Using Northern Haiti as a case study, we will characterize the users of an existing CBS service to determine the user base in need of such services, identify changes to excreta-management livelihoods that would likely occur with the

¹ The World Health Organization Joint Monitoring Programme's sanitation ladder ranks sanitation technologies based on safety and privacy characteristics.

expansion of CBS, identify changes to excreta flows and sanitation coverage that could result, and describe barriers that must be removed for these benefits to be realized.

Research objectives

One of the longest-running providers of household CBS services, EkoLakay provides an ideal case for exploring CBS and its role in urban sanitation systems of low-income cities. Based on household interviews with EkoLakay users in Cap Haïtien, this study addresses the following research questions:

- What are the characteristics of households that subscribe to the EkoLakay CBS system?
- What factors (including household, environment, social, and governance-related factors) affect households' decision to subscribe to EkoLakay?
- How do users of the EkoLakay CBS system perceive it in comparison to other available sanitation options?
- What are the implications of a CBS-integrated urban sanitation system on the exposure, labor hours, and livelihoods of northern Haiti's bayakou (professionals who manually excavate latrines and cesspits)?

Study context

The sanitation crisis is particularly acute in the country of Haiti. In 2014, a quarter of the Urban Haitian population lived in impoverished informal communities ([World Bank World Development Indicators 2018b](#)), and as of the most recent assessment by the WHO, nearly 20% of the population have no access to sanitation facilities ([World Bank World Development Indicators 2018a](#)). Although an estimated 81% of the Haitian population has access to a toilet or latrine, these technologies are rarely connected to a sanitation system for treating the excreta before release into the environment. Haiti ranks among the lowest 20 countries in the world for urban sanitation coverage, with less than 1% of the country's excreta and wastewater safely treated ([WHO Joint Monitoring Programme 2017](#)). The only safely managed sanitation available in the Cap Haïtien metropolitan area, where this study takes place, is a CBS service, EkoLakay ([Table 1](#)).

In communities with adequate road infrastructure, cesstanks can be emptied mechanically by pump vehicles. However, the density of pit latrine solids and inaccessibility of many dense, low-income environments makes mechanical excavation impractical, so these latrines must be excavated manually ([Neiburg & Nicaise 2011](#); [World Bank 2018](#)). While there has been significant work to improve latrine pumping technology, solutions have still not adapted to the context of most dense urban informal settlements ([Kabange & Nkansah 2019](#)). As of 2017, 55.7% of urban Haitians relied on latrines ([WHO Joint Monitoring Programme 2017](#)).

While the work of the bayakou – those that manually excavate latrines in Haiti – is essential to community health, the job itself is stigmatized. These professionals work under cover of night, brokering their services through a middle party to protect their identity ([Neiburg & Nicaise 2011](#); [World Bank 2018](#)). There are no regulations governing the working conditions of manual excavators, who often perform their work submerged in human excreta and chemical solvents, without equipment to protect them against disease or injury ([Lozano-Gracia & Garcia Lozano 2018](#); [World Bank 2019](#)). In addition, Northern Haiti has no sewage treatment facilities, and the nation lacks regulations to ensure that fecal sludge is disposed of properly; leaving manual excavators to dispose of pit sludge in open land, waterways, and/or the sea ([Sklar & Faustin 2017](#); [Mazars & Earwaker 2019](#)).

In 2017, diarrhoeal disease was the fifth leading contributor to loss of life in Haiti, at a rate of 20.5 years of life lost (YLL) for every 1,000 people in the country ([Fene et al. 2020](#)). About half of the diarrhoeal disease burden in Haiti is attributable to inadequate excreta management ([WHO 2018](#)). The structure of Haiti's sanitation landscape creates risk for households, the public, and essential workers who manage sanitary wastes. Haiti is unlikely to achieve the UN's SDG 6, 'to end open defecation and ensure safe and equitable sanitation for all' by 2030 ([UN General Assembly 2015](#)), and significant changes would be necessary to realize a sanitation system sufficient for the protection of public health.

One of the only safely managed sanitation options in Haiti is a CBS service, EkoLakay.² Operating for 7 years at the time of this study, EkoLakay serves neighborhoods that are flood-prone, densely populated, urban or peri-urban, and have low sanitation coverage and income levels. EkoLakay's CBS service provides a urine-diverting container-based toilet to households on a monthly subscription basis. Subscribers pay a monthly service fee of

² In Port au Prince metropolitan area, a small number of flush toilets are connected to a treatment plant.

Table 1 | Reported sanitation options available in metro Cap Haïtien, Haiti

WHO JMP sanitation ladder categories		Options available in Cap Haïtien, Haiti	
Improved sanitation	Private improved sanitation	Safely managed facilities	• EkoLakay CBS service
		Basic facilities	• Private latrine, flush, or dry toilet (no treatment after discharge)
	Non-private improved sanitation	Limited facilities	• Shared or public latrine, flush, or dry toilet (no treatment after discharge)
Unimproved sanitation		Unimproved facilities	• Shallow pit • Pit with no slab
Open defecation		No facilities	• In a bag • In a field • By the river

200 to 300³ Haitian gourdes (2.11 to 3.15 USD in August 2019) for rental of the portable toilet structure and weekly container exchange. The EkoLakay toilet houses a sealable five-gallon container that receives solid excreta, as well as a one-gallon jug that receives liquid waste through a urine-diverting funnel in the seat structure. After users defecate, they cover the fecal matter with a dry carbon-based cover material. This cover material is made from agricultural byproducts (currently ground sugarcane bagasse) and is provided by EkoLakay during the weekly exchange of full excreta containers for sanitized containers containing cover material. Users dispose of urine (which has a comparably negligible pathogen load) locally, reducing the volume and weight of excreta to be transported and treated. EkoLakay transports the sealed, containerized excreta to a compost treatment site where trained staff, equipped with personal protective equipment (PPE), transform the material through thermophilic composting. Studies of possible points of contamination along the CBS value chain have found that exposure risk is far below that of manual pit emptying (Mackinnon *et al.* 2018; Bischel *et al.* 2019). As a formal business, SOIL is able to implement training and strict safety protocols (SOIL 2019), providing all employees with PPE, health checks, and vaccinations. The final compost product is laboratory-tested for quality and safety before being sold to local consumers.

Globally, CBS services are largely delivered by non-governmental actors, and most operate at a small scale relative to municipal sanitation services. This arrangement is affected by multiple system characteristics: division of cost burden, scale of operation (EY 2020), and policy/regulatory barriers (Mara 2018). Recent research indicates that the true cost of CBS service delivery is lower than that of centralized sewerage (EY 2020; Delaire *et al.* 2021). The cost of sewerage is largely borne by the municipality, even if only through historical investment in infrastructure (Bhagwan *et al.* 2019). Private entities providing sanitation services like CBS must pass the full cost on to the consumer, or seek supplemental funding from other parties. Considering that users of CBS services are often resource-insecure households, this asymmetrical cost structure exacerbates existing inequities. Among strategies for implementing the CWIS framework, targeted subsidies and public-private partnerships can mitigate such inequities. Funding structures based on sanitation coverage outcomes will increase accessibility of CBS services and strengthen urban sanitation systems.

Another key barrier to the implementation of CBS services are regulatory structures in place. In many areas, sanitary regulations do not include safe alternatives to traditional sanitation infrastructure, and sometimes, the areas regulations expressly forbid excreta reuse or manual collection of waste flows. Existing CBS services must either adapt their operational model to work within existing regulatory frameworks, or work with governing agencies to modify regulations (World Bank 2019).

Community sanitation coverage is affected by interacting complex systems at multiple scales. To gain insight into the potential for CBS to achieve long-term sustainability, we seek to understand the users of this sanitation system. Understanding CBS at the user scale will allow insight into how larger scales of system management,

³ Payment structure details in Supplementary Material, Table S1.

including governance, financing, and physical infrastructure, influence and are influenced by characteristics of the user base.

As a component of a CWIS approach to sanitation in LMICs, CBS may facilitate progress toward multiple SDGs. By characterizing the user base of a long-running CBS service, and understanding what household and broader-system characteristics drive users to subscribe, we can contextualize the role that CBS plays, and can play, in the ability of low-income urban residents to maintain access to improved sanitation. By calculating selected impacts of expanding CBS service, we hope to understand the potential that this innovative sanitation approach holds for the health and wellbeing of the sanitation workforce. Considering the potential of CBS alongside barriers to widespread expansion, we can conceptualize a path toward optimizing urban sanitation systems in LMICs and toward a goal of safety, health, and equity.

METHODS

Research team and tools

This study used a mixed methodology approach (Greene 2007), deriving qualitative and quantitative data from EkoLakay subscriber records and structured interviews with active and former subscribers of the EkoLakay CBS service. Primary data was collected by a Haitian team involved in the development of the research instrument. To understand user relationships with CBS and the broader sanitation system, we developed a structured household survey that included open- and closed-ended questions. Interview questions and prompts were structured around self-reporting of all parameters, for consistency of results regardless of telephone or in-person interview format. All research staff training, tool-development, interviews, and other respondent interactions were conducted in Haitian Kreyol.

To answer questions about the safety, dignity, and employment implications of widespread CBS adoption, we compiled secondary data on Northern Haiti's urban population and their sanitation coverage; technical conditions of manual pit latrine excavation, excreta-handling labor and livelihoods; annual fecal generation values (see Supplementary Material, Table S3 for data sources and analysis); EkoLakay subscriber-to-excreta handler ratios; and service scale economies. From these variables, we calculated the volume of excreta produced by latrines in the urban areas of Haiti's Nord Department; the number of exposure events and cumulative hours of unsafe manual excreta handling that could be replaced by safely managed handling of containerized excreta; and the replacement ratios of working hours and livelihoods that would result from incorporation of CBS into urban sanitation systems in the Cap Haïtien area.

Household sample selection

At the start of data collection in August 2019, there were 1,008 households actively enrolled in the EkoLakay service, and 1,323 former-subscriber households. SOIL provided lists of former and active EkoLakay subscribers for whom telephone contact information was available. To ensure that active subscribers would have sufficient exposure to EkoLakay to answer questions about their experience and satisfaction, we filtered out subscribers who had enrolled after April 30, 2019. We further eliminated households of SOIL employees. The total number of potential participants meeting these criteria was 1,199 former and 733 active subscriber households.

We randomized the lists of active and former subscribers and assigned each household a confidential identifier. Research staff recruited participants by phone, and scheduled interviews with a single household decision maker over 18 years.⁴ Respondents who had moved away from the Cap Haïtien area, or were unwilling to meet in-person, were offered the opportunity to be interviewed by phone.

DATA COLLECTION AND ANALYSIS

Data collection

Members of the team that developed the survey instrument also served as interviewers. Interviewers collected survey responses using Qualtrics® (Qualtrics, Provo, UT) on a handheld smartphone. Responses were accessible only to investigators, after uploading to secure storage at the end of each day. From August 24 to October 6, 2019, the team conducted 633 structured household interviews. Interviewers obtained and documented verbal

⁴ Haitian households rarely recognize a single household head; they are more likely to have multiple adult members engage in financial decision making.

acknowledgement of informed consent. Interviewers identified themselves, in person and by telephone, as representatives of an independent research group with no affiliation to EkoLakay. Due to significant disruption to statewide transportation and energy infrastructure, in mid-September our field team ceased household visits and completed the remaining 286 interviews by telephone. Recruitment methods did not change during this period; interviewers continued to schedule willing respondents for an interview date and time, but did not offer the option of a home visit.

Initial survey prompts identified household population by age group and sex, the number of rooms in the home, and how long the respondent had lived in the home (see Supplementary Material, Table S4 for complete questionnaire). Closed-ended questions addressed property and household characteristics, as well as satisfaction questions based on a Likert scale and household expense questions (questions fully described in Supplementary material). Open-ended questions addressed subjective perceptions and preferences. These questions were left open-ended to capture unanticipated variability in the respondent population. Interviewers categorized these responses in the field using predefined codes, summarizing responses that did not fit the available codes for later categorization by investigators.

Data transformation

After all data had been collected, investigators assigned uncategorized responses to appropriate codes. In some cases, new categories were necessary to house these responses. Investigators further aggregated categorical responses through an iterative process of team-based coding (Tolley *et al.* 2016). To compare pre-subscription household sanitation of EkoLakay users to the general Haitian population, responses were aggregated into categories associated with the WHO sanitation ladder (Table 1).

Household density was calculated as the quotient of reported household members per reported room in the home. Reported expenses and frequencies, along with the currency exchange rate average for the month of their interview, were used to calculate estimated monthly electricity, phone, and transportation expenses in USD. From EkoLakay's full list of active and former subscribers, we calculated the average cumulative time that households remain subscribed to the EkoLakay service. In the case of active subscribers, cumulative time was calculated as the difference between the contract open date and August 24, 2019. We used the respondent's reported residence time and their start-of-service date to calculate the approximate duration of residence at the time they opened their EkoLakay subscription.

Data analysis

While this study collected responses from both active and former subscribers to the EkoLakay CBS service, some analyses in this report involve only active subscribers. When characterizing subscriber households, we use only active respondent data. When analyzing reported reasons for subscribing to the service and pre-subscription household sanitation, we use data from both active and former-subscriber respondents.⁵

Our respondent sample included only households and individuals who had subscribed to EkoLakay at some point in time, and as a result, there is no comparison group of general Haitian households in this study. Thus, household demographic and property data were sourced from publicly available national and international datasets (UN Department of Economic and Social Affairs, WHO/UNICEF Joint Monitoring Programme, USAID Demographic and Health Surveys, and World Bank) for comparison purposes. To compare proportions (e.g., sanitation access types, residence status, and utility access) between active EkoLakay subscriber and urban Haitian households, we used a one-sample proportions test. To identify a difference in household size between EkoLakay subscribers and the average urban Haitian household, we conducted a two-tailed *t*-test.

To determine whether selected household characteristics correlated with household sanitation status prior to opening an EkoLakay subscription, and to determine the likelihood of reported motivations falling into each code category, we performed odds ratio analysis. Where analysis involved large counts, we used Pearson's Chi-square test. For analyses involving cell counts below ten, we used Fisher's exact test. To compare continuous household variables to reported motivations, we applied logistic regression. All statistical analyses were performed with R 22.0 (R Core Team 2020).

⁵ Analysis of data showed that this transition did not yield significant differences between groups (full details in Supplementary material).

RESULTS AND DISCUSSION

Secondary data analysis: human rights and work in the sanitation sector

A 2018 report estimated that the sanitation system of the Port au Prince, Haiti metropolitan area supports 270 manual excavation livelihoods (World Bank 2018). Based on the population (IHSI 2015) and household density (Institut Haïtien de l'Enfance – IHE/Haiti & ICF 2017) of this metropolitan area, proportion of the regional urban population using latrines (WHO Joint Monitoring Programme 2017), and a conservative latrine-emptying frequency of 4.5 years (Sklar & Faustin 2017), we estimate a ratio of 0.001 manual emptying professionals per latrine-using household. Furthermore, reports of manual excavators' team structure and working hours indicate an average team of three to four professionals working for two to three nights per latrine emptied (Reed 2010; Neiburg & Nicaise 2011; Lozano-Gracia & Garcia Lozano 2018; World Bank 2019). Assuming 2.5 professionals per team and the population of urban Nord Department using latrines, we estimate 42,000 manual pit-emptying exposure events per year; and with 16 h per job, this translates to over 800,000 annual hours of direct exposure by manual emptying professionals in the urban areas of the Nord Department.

In contrast, EkoLakay currently operates at a rate of 0.016 CBS excreta-handling professionals (collection and processing) per household. Assuming an 86% increase in efficiency brought about by increases in scale and customer density (Boyer *et al.* 2009), if latrine-using households instead adopt CBS, this would yield a replacement ratio of two CBS excreta handlers per manual excavator (Table 2; detailed calculations in Supplementary Material, Table S3). Furthermore, based on urban Nord Department latrine users, the equivalent sanitation coverage, provided by CBS services, would support over 500 safe excreta-handling livelihoods. An additional 100 plus livelihoods would be created if CBS was extended to the 20% of Haitian households who currently lack sanitation altogether (Table 2; detailed calculations in Supplementary Material, Table S3). Thus, a transition to CBS would replace unsafe labor conditions with safe and reliable livelihoods and potentially increase employment opportunities while dramatically reducing exposure to sanitation workers. These changes would lift multiple community members from circumstances undermining the human right to sanitation, as well as safe and dignified employment. Many previous international efforts to improve the working conditions of manual excavators have been deemed unsuccessful and abandoned (World Bank 2018). While political systems may lack the enforcement resources to protect independent workers, CBS services provide a structure compatible with safety monitoring and worker protection, and confer dignity to employees (Tilmans *et al.* 2015). CBS is gaining recognition around the world, and recent research has taken on the question of scaling these operations and integrating them with inclusive sanitation planning (Shepard *et al.* 2017; Russel *et al.* 2019; EY 2020). From a systems perspective, the social benefit of a stable and increased employment base in the community is created by CBS expansion.

Table 2 | Potential impact of expanding CBS in Cap Haïtien metropolitan area

<i>Extending EkoLakay CBS service to homes without sanitation</i>	
Persons transitioning from open defecation to safely managed sanitation	53,000
Annual excreta safely managed (metric tonnes)	600
Safe excreta-handling livelihoods created	100
<i>Replacing latrines with EkoLakay CBS service</i>	
Persons transitioning from unsafe to safely managed sanitation	288,000
Annual excreta safely managed (metric tonnes)	3,300
Safe excreta-handling livelihoods created	500
Person-exposure-events per year avoided in urban Nord	41,700
Hours direct exposure avoided per year	853,000
CBS/Bayakou livelihoods ratio	2.0
CBS/Bayakou working hours ratio	1.2

All figures are the result of calculations based on secondary data sources. Full calculations and source citations are available in Supplementary Material Table S3.

Primary household data collection: response rate, confidence, and representativeness

Due to a high rate of inactive phone numbers, it became necessary to attempt contact with all active and former subscribers to achieve an adequate sample size. Of 733 active subscribers, we made contact with 383 subscribers, 9 of whom declined to participate, and 49 were unable to be scheduled; thus resulting in an active subscriber completion rate of 84.5% for a sample $n = 325$, with a 4% margin of error at the 95% confidence level. Of the 1,199 potential former subscribers, we successfully contacted 406 former subscribers, 30 of whom declined to participate, and 68 were unable to schedule; thus resulting in a former-subscriber completion rate of 75.9% for a sample of $n = 308$, with a 5% margin of error at the 95% confidence level. Sample sizes vary by analysis, as respondents could decline to answer any prompt.

Where are EkoLakay users?

The EkoLakay service area spans four communes in the Cap Haïtien metropolitan area, spanning a range of urban and peri-urban sites (map and further details in Supplementary material). All neighborhoods serviced by EkoLakay are characterized by low infrastructure and high poverty (Russel *et al.* 2015). The flood-prone nature of many of these zones is an important factor in their inclusion in the EkoLakay service area. The EkoLakay toilet container sits above the ground, protecting it from water intrusion in minor flood events, and can be sealed to secure against excreta release in the case of extreme flooding or other disruption.

Who are EkoLakay users?

Household demographics

The sex ratio of active EkoLakay subscriber households matches the Haitian distribution ($p = 1.000$), as does the distribution of age groups across households ($p = 0.987$) (Table 3). Active EkoLakay subscriber households are larger than the national urban average, at 5.1 persons per household, compared to the 2017 urban Haitian average of 4.4 ($p < 0.001$). Household density varies from as few as one person to as many as eight persons per reported room in the house, with an average density of 2.2 persons per room (Table 3). This provides insight into the resource strain of the EkoLakay subscriber base. In addition to general resource strain, highly populated households may also experience pressure on existing sanitation infrastructure, requiring an alternative or auxiliary sanitation option.

Resource access

Nearly 10% of active subscriber respondents report living in an unauthorized informal dwelling, such as a temporary shelter constructed on public or privately owned land. This number is 48 times higher than the 2003 urban Haitian population ($p < 0.001$). Active subscribers are less likely to report renting their home ($p < 0.001$) and more likely to report owning their home than the 2003 urban Haitian population ($p < 0.001$) (Table 3).⁶ Homeownership statistics should be contextualized; as of 2010, only 40% of Haitian landowners possessed a legal title to their property, or formal documentation of land ownership (USAID 2010). With this in mind, and given the vulnerable state of the neighborhoods that comprise EkoLakay's service area, respondents reporting homeownership may only own the structure itself, or have otherwise insecure tenure on their land. Furthermore, this vulnerability is not temporary. Active subscriber respondents reported residence times of up to 70 years, with a mean residence time of 12.2 years. One EkoLakay service area, an informal community of over 50 years, was leveled without warning by the municipal government since the time of this research.

Active subscribers describing their household sanitation situation circumstances immediately prior to accessing EkoLakay reported higher rates of open defecation ($p < 0.05$), higher rates of non-private improved sanitation use ($p < 0.05$), and lower rates of private improved sanitation ($p < 0.001$) than the national urban average (Table 3; Supplementary Material, Figure S3). Upon subscribing to EkoLakay, 29% of households gained sanitation where they had previously lacked any toilet access; 39% of households gained privacy, and all subscribers gained safely managed sanitation status.

Active EkoLakay subscribers are only two-thirds as likely to have access to electricity as the average urban Haitian household ($p < 0.001$).⁷ Active subscribers did not differ from the urban national average in access to on-site

⁶ Subsequent to 2003, national demographic surveys did not include residence status statistics.

⁷ It is not clear whether the SE4ALL dataset considers households with generators among those considered to have access to electricity. However, regardless of whether generators are included in this grouping, the statistical significance of this finding remains the same.

Table 3 | Household characteristics of EkoLakay subscribers vs. Urban Haitian population

	EkoLakay subscriber households (2019)	Urban Haiti (2017)	p-value
Respondent sex ratio (M:F) (household spokesperson, active and former-subscriber respondents; <i>n</i> = 633)			
Individual respondents	46%:54%	49%:51%	<i>p</i> = 0.086
Household sex ratio (M:F) (active subscriber respondents; <i>n</i> = 322)			
Whole household	49%:51%	49%:51%	<i>p</i> = 1.000
Household size (active subscriber respondents; <i>n</i> = 322)			
Household members	5.1	4.4	<i>p</i> = 5.74 × 10 ^{-06***}
Household composition (active subscriber respondents; <i>n</i> = 322)			
Adult women	1.7	1.5	<i>p</i> = 0.987
Adult men	1.4	1.1	
Youth ages 5–17	1.5	1.4	
Children under 5 years	0.4	0.5	
Households with 1 or more members with a disability or chronic illness	34.2%	–	
Households with youth ages 5–17	72.6%	65.1%	<i>p</i> = 5.02 × 10 ^{-131***}
Households with children <5 years	31.4%	35.4%	<i>p</i> = 8.78 × 10 ^{-40***}
Household density (active subscriber respondents; <i>n</i> = 322)			
Persons per room in house	2.2	–	
Household resources (active subscriber respondents)			
Has access to electricity (<i>n</i> = 314)	grid-connected electricity: 52.2% grid and/or generator: 59.9%	(2018) 78.2%	<i>p</i> = 3.95 × 10 ^{-51***} <i>p</i> = 6.32 × 10 ^{-15***}
Has on-site water (<i>n</i> = 314)	(includes cistern for delivered water) 24.8%	20.5%	<i>p</i> = 0.065
Has bank account (<i>n</i> = 321)	41.1%	37.1%	<i>p</i> = 0.147
Has no formal money-management system	12.8%	–	
Residence status (active subscriber respondents; <i>n</i> = 306)			
Own	71.7%	(2003) 55.9%	<i>p</i> = 1.38 × 10 ^{-08***}
Rent	15.5%	(2003) 40.6%	<i>p</i> = 7.81 × 10 ^{-20***}
Informal (authorized)	3.1%	(2003) 3.3%	<i>p</i> = 1.000
Informal (unauthorized)	9.6%	(2003) 0.2%	<i>p</i> = 1.40 × 10 ^{-252***}
Mean residence time (years)	12.2	–	
Household sanitation prior to subscribing (active and former-subscriber respondents; <i>n</i> = 619)			
Open defecation or unimproved sanitation	29.4%	19.4%	<i>p</i> = 0.012*
Non-private improved sanitation	39.2%	36.8%	<i>p</i> = 0.013*
Private improved sanitation	31.2%	43.8%	<i>p</i> = 2.01 × 10 ^{-05***}

Dark gray field indicates a higher value than the urban Haitian average

Light gray field indicates a lower value than the urban Haitian average

*Significant at a 0.05 level.

**Significant at a 0.01 level.

***Significant at a 0.001 level.

Haitian household and demographic data from Haiti Demographic and Health Survey 2016–17 Dataset.

Haitian electricity access data from World Bank, Sustainable Energy for All (SE4ALL) database.

p-value for percentages is the result of a 1-sample proportions test with continuity correction (1 df).

p-value for means is the result of a 1-sample *t*-test against the Haitian average (*n* – 1 df).

p-value for household composition is a result of Pearson's Chi-square test against the Haitian distribution (3 df).

Sample sizes vary by analysis due to nonresponse.

water in the form of a well, cistern, or piped water (Table 3). The majority of active EkoLakay subscriber respondents (61%) reported having none of the selected amenities used as a proxy for wealth in this study (generator, indoor shower, inverter, solar panels, water cistern on house, well), further illustration of the marginal economic status of EkoLakay subscriber households.

Household financial practices

The EkoLakay service operates on a subscription basis, with fees collected monthly. This payment structure is somewhat unique in the Haitian context and may play a role in the accessibility of the service to some users. To better understand the EkoLakay subscriber population, we gathered information on financial practices, including frequency of payments for various necessities.

Household expenses varied broadly within each reported category. It is possible that the most recent week or payment interval did not represent a respondent's average expenses (the country experienced a gas shortage and political unrest during the data collection period), and/or that respondents' memory or estimations were flawed. Furthermore, respondents may have interpreted this inquiry differently, reporting family or personal transportation expenses depending on their individual role in family finances. Comparing these monthly expenses to the cost of EkoLakay, however, can contextualize its role in household finance.

The average subscriber was more likely to pay for sanitation as opposed to electricity; two-thirds of subscribers report no electricity expenses, though this finding does not parse out whether electricity services were readily available (note: these figures do not include fuel costs for the 8% of active subscribers who have generator-powered electricity at home). The relative burden and/or priority of communication expenses, however, averages 1.5 to 3 times the cost of an EkoLakay subscription (Figure 1(a) and 1(b); note that the y-axis on visual comparisons is log scale). Transportation is by far the highest monthly service expense incurred by subscribers during the study period, averaging 10 to 17 times the cost of EkoLakay service (this figure may have been heavily impacted by the fuel shortage, as it exceeds the ratio observed by researchers in 2015 (Russel, personal communication February 13, 2021)). The majority of Cap Haïtien residents do not own a personal vehicle, so transportation expenses largely describe fees for transit by multi-passenger vehicle or motorcycle taxi.

Why do households subscribe to EkoLakay?

Themes and specific reasons

There were 324 active subscribers and 306 former subscribers to the EkoLakay CBS service who responded to the open-ended question. Do you remember why you chose to join the EkoLakay service? Responses to this question were coded into 14 categories at the time of interview. Responses that did not fit one of the existing codes were described in an open-text 'other' field. From these descriptions, six new categories were created by investigators. On review of all responses, six major themes emerged to describe factors affecting the decision to open an EkoLakay subscription. Themes indicated relationships to economic, social, governance, and technical systems.

The majority (60%) of all respondents cited some form of cost and resource savings as their major motivation for subscribing to EkoLakay. This was followed by quality of life themes (40%), health, cleanliness, and security themes (27%), favorable comparison to existing or other options (15%), external influence (6%), and targeted or auxiliary use of the technology (4%) (Table 4).

Within the cost and resource savings theme, well over half of respondents (57%) stated that they subscribed to EkoLakay because they lacked the resources to invest in permanent sanitation infrastructure (Table 4). This is an indication that EkoLakay fills an existing sanitation gap; it meets the needs of those who seek private improved household sanitation but do not have the economic means of attaining other options on the 'market'. As cost and resource savings was mentioned by 60% of all respondents, former and active, it is evident that EkoLakay is serving an important role in household economy for low-income subscriber households in Cap Haïtien. In many cases, it appears to be the only accessible form of private sanitation. In others, it is a valuable tool that allows the household to free up needed financial resources for other important expenses.

Within the quality of life theme, 30% of respondents described having a private toilet as a key reason for subscribing to EkoLakay. A further 15% simply mentioned improvements to quality of life in general (Table 4). Many responses categorized in this way included the simple phrase, to have a toilet. Such a statement implies that the household, prior to their EkoLakay subscription, lacked fundamental resources for meeting their basic human needs. Rights pertaining specifically to sanitation have been reiterated and clarified twice by the United Nations (UN Committee on Economic Social & Cultural Rights 2010; UN General Assembly 2016). Based on our

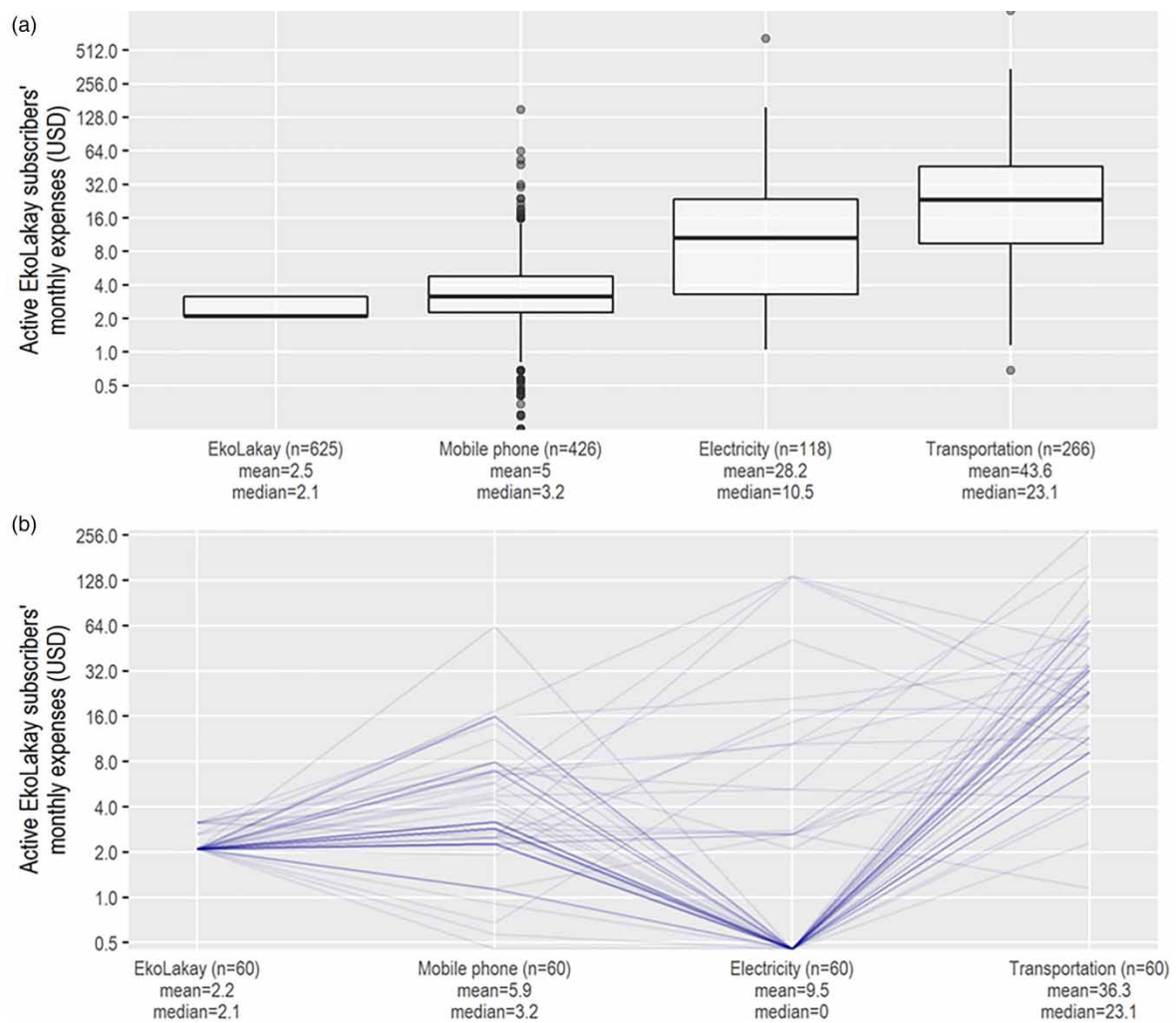


Figure 1 | (a) Active EkoLakay subscribers' monthly expenses in USD (not including respondents without Electricity); (b) Relative priority of EkoLakay compared to other monthly service expenses in USD (including respondents without access to Electricity). Each line represents an individual household. Only those households reporting all four categories are included in this visualization.

findings, over a third of EkoLakay subscribers have no technological or infrastructure alternative for meeting their sanitation needs. For citizens whose sanitation needs remain unmet, CBS may be an accessible tool for use by the Haitian government as they work to secure the basic rights of their citizens.

Among reasons categorized under health, cleanliness, and security, the most-cited motivation for subscribing to EkoLakay was cleanliness, cited by 15% of all respondents (Table 4). This continues to illustrate the vulnerable condition of EkoLakay subscriber households, as well as the important role that CBS is serving in protecting health and meeting basic needs. The specific mention of community environment by 10% of all respondents indicates recognition of individuals' role in community health, and the value of CBS access in advancing the wellbeing of their community. This indicates the influence of social factors in sanitation decision making, and suggests a potential for community-led initiatives to drive demand for CBS in the region.

The dominant response categorized as favorable comparison to existing/other options was that the household was unable to resolve an issue with their existing sanitation technology⁸ (14% of all respondents) (Table 4). This challenge may have been technical or financial in nature, or the result of a landlord's failure to maintain the sanitation infrastructure. Sanitation scholars have documented the prevalence of unusable latrines in urban Haiti, subject to disputes over stewardship responsibility between tenants and landlords (Neiburg & Nicaise 2011), and our respondents provide further evidence of the extent of this challenge. Responses within this theme further

⁸ Such issues may also include unreliable water and electricity access, necessary to gravity cistern function.

Table 4 | Cited factors affecting decision to subscribe to EkoLakay (*n* = 630)

Themes; specific reasons	respondent count	% within theme	% of all respondents
Cost and resource savings	378		60%
To save water	4	1.1%	0.6%
To save money	9	2.4%	1.4%
Cheaper than other options	25	6.6%	4.0%
Don't have the money to build another san option	360	95.2%	57.1%
Quality of life	251		39.8%
To improve quality of life	92	36.7%	14.6%
To have a private toilet	189	75.3%	30.0%
Health, cleanliness, and security	171		27.1%
Security	32	18.7%	5.1%
Health	58	33.9%	9.2%
To improve/protect community environment	63	36.8%	10.0%
For cleanliness	93	54.4%	14.8%
Favorable comparison to existing / other options	97		15.4%
Better system/service than other options	9	9.3%	1.4%
Problem with management of existing sanitation	89	91.8%	14.1%
External influence	38		6.0%
Was offered a subsidy	1	2.6%	0.2%
Felt under pressure by neighbors/others	8	21.1%	1.3%
Positive influence of others	29	76.3%	4.6%
Targeted or auxiliary use	23		3.7%
Visitors	2	8.7%	0.3%
For semi-public use (church, school, or business)	3	13.0%	0.5%
For renters	4	17.4%	0.6%
Temp solution awaiting permanent sanitation infrastructure	4	17.4%	0.6%
Household member with illness or limited mobility	10	43.5%	1.6%
All respondents	630		

Cumulative column sums may exceed total respondent count, as respondents could offer up to three 'reasons' for subscribing.

build on the indications that the technological landscape of the Cap Haïtien metro area offers few options for households to access safe, reliable sanitation. Thus, EkoLakay appears to be filling this gap, and if CBS services were subsidized or otherwise made more accessible to low-infrastructure and resource-strained households, the system may be able to alleviate a portion of exigent community needs.

External influence was cited by 6% of respondents (*n* = 38) as a factor in their decision to subscribe. Most of these responses referred to the positive influence of others, while some also expressed that they felt pressure from community members to subscribe. These responses provide evidence of the role of social systems in sanitation decision making.

Of the subscribers who reported having obtained an EkoLakay toilet for a targeted or auxiliary use, nearly half (1.6% of all respondents) did so to provide accessible sanitation to a household member with illness or limited mobility. While this targeted purpose was mentioned as a primary driver for a smaller segment of the user population, the portability and small footprint of EkoLakay's CBS technology may be a meaningful advantage for the 34% of respondents who reported having a household member living with a disability or chronic illness (Table 3). Furthermore, this theme illustrates that CBS has the potential to fill another unique market gap – that of increasing accessibility, privacy, and convenience for households whose basic needs are already met. While EkoLakay has not historically targeted such households (Russel *et al.* 2015), such a clientele could be a valuable subscriber segment in CBS service delivery models.

Relationships between household characteristics and motivations for subscribing

Subscribers who previously practiced open defecation were more likely than the average respondent to mention quality of life ($p < 0.001$) and health, cleanliness, and security ($p < 0.001$) among reasons for subscribing to EkoLakay, while those who previously had access to private improved sanitation were less likely to cite these themes ($p < 0.01$; $p < 0.001$) (all calculations in Supplementary Material, Table S7). These responses display a

continuous-style relationship along the sanitation ladder; evidence that the severity of quality of life and health, cleanliness, and security-related concerns decreases as a household accesses increasingly safe, reliable, and private sanitation. A subscriber coming from a situation without sanitation and/or privacy is motivated strongly by these concerns, while other factors are more likely to affect decision making for households who have maintained sanitation access. Furthermore, the probability of mentioning quality of life among reasons for subscribing to EkoLakay is positively correlated with household density (persons per room in home) (coef = 0.199, $p = 0.002$) (Supplementary Material, Figure S4). This may be a response to the difficulty of securing privacy in a dense living environment. It is also possible that densely populated households are characterized by heightened resource scarcity, leading to priorities associated with more basic human needs.

When comparing EkoLakay favorably to other sanitation options, we found that preference for EkoLakay is positively correlated with residence time (coef = 0.003, $p = 0.004$) (Supplementary Material, Figure S5). It is likely that this relationship reflects the condition of existing infrastructure in long-term residences and completed homes. Aging sanitation infrastructure may malfunction or require expensive maintenance or emptying. Over half of respondents comparing EkoLakay favorably to alternatives already had some form of private sanitation in the home.

CBS user satisfaction and future sanitation aspirations

While EkoLakay subscribers expressed a general preference for flush toilets (VanRiper 2021), the majority of former and active subscribers (87%) also report satisfaction with their household EkoLakay CBS experience (Table 5).

This high rate of satisfaction illustrates that CBS is not only filling a critical sanitation gap, but is an agreeable experience for subscriber households. Inadequate sanitation is more than an inconvenience; disease caused by poor sanitation interrupts livelihoods, earning opportunities, and education (Santiago Ortiz-Correa *et al.* 2016; WHO 2018). The ability of the EkoLakay CBS service to meet immediate household sanitation needs without major expenditures may allow resource-insecure households to maintain a basic quality of life while pursuing economic advancement that would enable them to invest in their preferred sanitation.

These CBS users demonstrate that CBS is a priority for many households, most of whom choose to pay for the service. These subscribers are part of a social system of extreme poverty in which they are trying to improve their quality of life with minimal investment and careful financial prioritization. They understand the importance of improved sanitation in terms of safety, convenience, and cleanliness, but despite the obvious preference and benefits to the social system, this is linked to other systems of governance and infrastructure that impede the full realization of the social benefits.

CONCLUSION

This study provides insights into the potential for CBS as a tool for achieving multiple Sustainable Development Goals. CBS has the potential to strengthen sanitation systems in LMICs, extending the human right of safe sanitation to the most vulnerable households while also protecting the health and dignity of sanitation professionals.

Table 5 | Reported satisfaction with EkoLakay CBS experience, by subscriber status ($n = 625$)

	Respondent count (% of column)		
	Former subscribers	Active subscribers	Grand total
Absolutely satisfied	56 (18.7%)	60 (18.5%)	116 (18.6%)
Satisfied	205 (68.3%)	225 (69.2%)	430 (68.8%)
Neither satisfied nor dissatisfied	33 (11%)	35 (10.8%)	68 (10.9%)
Not satisfied	5 (1.7%)	5 (1.5%)	10 (1.6%)
Not at all satisfied	1 (0.3%)	0 (0%)	1 (0.2%)
Grand total	300	325	625

The human rights implications of these findings are promising; internationally, many communities share similar challenges and opportunities to those observed in northern Haiti. In urban areas where permanent infrastructure is not feasible, accessible, or functional, CBS could meet the need for safe sanitation, a human right recognized by the UN. In addition, CBS expansion has implications for the wellbeing and human rights of the community workforce, the bayakou, that manually empty pit latrines exposing themselves to physical danger and stigma.

Despite the many benefits of CBS found in this study, large-scale implementation of CBS faces a multitude of systems barriers. A system-based approach to public sanitation, including integrating CBS into community-wide sanitation delivery models will enable aspects of social, governance, and technological systems to interact effectively, thus allowing the benefits of this innovation to reach those who need it most. First and foremost, CBS will need investment from the public sector. As shown in this study, users noted cost and resource savings as a key motivator for subscribing to CBS services. CBS fills an important role in providing safe sanitation for those that do not have the resources for permanent forms of improved sanitation, but without subsidy those who desire CBS access may be unable to afford or remain subscribed to the service.

Just as CWIS calls for multiple technological approaches, the framework also recognizes that varied economic models are required to correct the market failures inherent to services that meet basic human needs (McGrathan 2015; Schrecongost *et al.* 2020). To achieve equitable sanitation coverage for the entire population, urban sanitation programs often need to be managed as a public service. Public investment in CBS as part of a CWIS portfolio could take many forms, from strategic public-private partnerships and blended financing models to full provision of services. Laguna Water, in the Philippines, uses water service fees from across the customer base to subsidize CBS service provision for low-income households (GHD 2018). As seen in this example, leveraging the potential of private sector collaboration will allow public entities to fund sanitation coverage for fragile context residents, including those living in areas of unclear land tenure.

Funding structures based on sanitation coverage outcomes could increase accessibility of CBS services and strengthen urban sanitation systems. With expansion, per-capita service delivery costs are likely to decrease, creating a positive feedback loop (EY 2020). Furthermore, public service providers investing in broad-scale CBS application may be able to avail themselves of atypical funding resources, such as carbon mitigation credits (Shaw *et al.* 2021) or other environmentally linked financial incentives, due to the unique characteristics of CBS technologies. Alternatively, with growing recognition of the ability for CBS to meet SDG 6.2 and human rights or alleviate some environmental pollution crises, emerging regulations or international agreements could create positive pressure to adopt CBS.

Support from the public sector is also necessary to dismantle policy-related obstacles to expansion of this appropriate technology. From clarifying recognition of CBS as a safely managed sanitation solution as has been done by the Kenya Ministry of Health (2016), to defining conditions and markets for safe reuse of excreta as seen in Ghana and multiple European countries (Jayathilake *et al.* 2019), coordination among governing entities can facilitate the ability of CBS to fill gaps in urban sanitation systems.

Other system-wide concerns include regulatory constraints and labor rights. Haiti lacks regulatory structures, and the capacity to enforce such regulation necessary to protect sanitation professionals' health, working conditions, or social wellbeing (World Bank 2018; Mazars & Earwaker 2019). Attempts to recognize the rights of latrine emptiers and improve their working conditions are likely to be insufficient, so long as the sanitation system is predicated on manual excavation of excreta. CBS technologies can safely separate both the user and processor from direct contact with excreta, and the semi-centralization of CBS operations enables service providers to implement training, safety protocols, and healthcare support for workers. Adoption of CBS as part of urban sanitation systems may be a useful precedent to addressing the health and human rights risks associated with manual latrine emptying.

Users of Haiti's EkoLakay CBS service represent extremely low-income households, over a quarter of whom have no other sanitation option within or outside the home. These subscribers represent only a fraction of the fifty-thousand households in the Cap Haitien metro area who lack access to sanitation infrastructure. Seven years into its existence as a household service, EkoLakay demonstrated a high rate of user satisfaction, but it will remain inaccessible to many, without public support and incorporation into a CWIS framework. CBS is a promising tool to help LMICs aim for 100% urban sanitation coverage, CBS has been integrated successfully with urban sanitation service delivery in some major cities, but its global potential as a component of CWIS has only begun. With investment and regulatory support from the public sector, CBS could become an essential component of urban sanitation systems, creating safe and dignified livelihood alternatives to manual emptying,

and extending the human right of safely managed sanitation to all for whom permanent infrastructure is not accessible, functional, or feasible. However, achieving this outcome will require approaches that effectively integrate the technical, regulatory, financial, and social components of urban sanitation systems; along with the public health goals of the public sanitation system, solutions will consider worker safety, social mores, affordability, climatological resilience, and technical reliability.

AUTHOR CONTRIBUTIONS

Froggi VanRiper: Conceptualization, Methodology, Validation, Formal analysis, Data Curation, Writing – Original Draft, Writing – Review & Editing, Visualization. Kory C. Russel: Conceptualization, Methodology, Supervision, Writing – Review & Editing. Daniel Tillias: Methodology, Supervision, Writing – Review & Editing. Jenna Tilt: Supervision, Writing – Review & Editing. Jessica Laporte: Methodology, Supervision, Project administration, Writing – Review & Editing.

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CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES

- Andersson, K., Otoo, M. & Nolasco, M. 2017 [Innovative sanitation approaches could address multiple development challenges](#). *Water Science and Technology* **77** (4), 855–858. <https://doi.org/10.2166/wst.2017.600>.
- Bhagwan, J. N., Pillay, S. & Koné, D. 2019 [Sanitation game changing: paradigm shift from end-of-pipe to off-grid solutions](#). *Water Practice and Technology* **14** (3), 497–506. <https://doi.org/10.2166/wpt.2019.059>.
- Bischel, H. N., Caduff, L., Schindelholz, S., Kohn, T. & Julian, T. R. 2019 [Health risks for sanitation service workers along a container-based urine collection system and resource recovery value chain](#). *Environmental Science & Technology* **53** (12), 7055–7067. <https://doi.org/10.1021/acs.est.9b01092>.
- Boyer, K. K., Prud'homme, A. M. & Chung, W. 2009 [The last mile challenge: evaluating the effects of customer density and delivery window patterns](#). *Journal of Business Logistics* **30** (1). Available from: <https://onlinelibrary-wiley-com.ezproxy.proxy.library.oregonstate.edu/doi/epdf/10.1002/j.2158-1592.2009.tb00104.x>
- Carr, R. 2001 Excreta-related infections and the role of sanitation in the control of transmission. In: *Water Quality: Guidelines, Standards & Health* (Fewtrell, L. & Bartram, J. eds). IWA Publishing, London.
- Clayton, T. & Radcliffe, N. 1996 *Sustainability: A Systems Approach*. Westview Press, Boulder, CO. <https://doi.org/10.4324/9781315070711>.
- de Albuquerque, C. 2012 *Report of the Special Rapporteur on the Human Right to Safe Drinking Water and Sanitation: Stigma and the Realization of the Human Rights to Water and Sanitation*. UN General Assembly Human Rights Council.
- Delaire, C., Peletz, R., Haji, S., Kones, J., Samuel, E., Easthope-Frazer, A., Charreyron, E., Wang, T., Feng, A., Mustafiz, R., Faria, I. J., Antwi-Agyei, P., Donkor, E., Adjei, K., Monney, I., Kisiangani, J., MacLeod, C., Mwangi, B. & Khush, R. 2021 [How much will safe sanitation for all cost? Evidence from five cities](#). *Environmental Science & Technology* **55** (1), 767–777. <https://doi.org/10.1021/acs.est.0c06348>.
- EY 2020 *How Cost Analysis Dispels Myths About Container-Based Sanitation*. London, UK. Available from: https://www.ey.com/en_gl/corporate-responsibility/how-cost-analysis-dispels-myths-about-container-based-sanitation
- Fene, F., Ríos-Blancas, M. J., Lachaud, J., Razo, C., Lamadrid-Figueroa, H., Liu, M., Michel, J., Thermidor, R. & Lozano, R. 2020 [Life expectancy, death, and disability in Haiti, 1990–2017: a systematic analysis from the Global Burden of Disease Study 2017](#). *Revista Panamericana de Salud Pública* **44**. <https://doi.org/10.26633/RPSP.2020.136>.
- Gambrill, M., Gilsdorf, R. J. & Kotwal, N. 2020 [Citywide inclusive sanitation – business as unusual: shifting the paradigm by shifting minds](#). *Frontiers in Environmental Science* **7**. <https://doi.org/10.3389/fenvs.2019.00201>.
- GHD 2018 *Portable Toilet Solutions Phase 2 Pilot Testing Report (No. 71/12564)*. Laguna AAA Water Corporation, Manila, Philippines. Available from: <https://forum.susana.org/media/kunena/attachments/11616/2018-04-19FinalReportwithoutAppendix.pdf>

- Greene, J. C. 2007 *Mixed Methods in Social Inquiry*. Jossey-Bass, San Francisco.
- Hyun, C., Burt, Z., Crider, Y., Nelson, K. L., Prasad, C. S. S., Rayasam, S. D. G., Tarpeh, W. & Ray, I. 2019 [Sanitation for low-income regions: a cross-disciplinary review](#). *Annual Review of Environment and Resources* **44** (1), 287–318. <https://doi.org/10.1146/annurev-environ-101718-033327>.
- IHSI 2015 *Population Totale, de 18 ans et Plus: Menages et Densites Estimes En 2015*. Institut Haïtien de Statistique et d'Informatique. Available from: https://web.archive.org/web/20151106110552/http://www.ihsi.ht/pdf/projection/Estimat_PopTotal_18ans_Menag2015.pdf
- Institut Haïtien de l'Enfance – IHE/Haiti and ICF 2017 *Haiti Demographic and Health Survey 2016–17 [Dataset]*. HTPR71.SAV. Available from: <https://dhsprogram.com/methodology/survey/survey-display-503.cfm>
- Jayathilake, N., Drechsel, P., Keraita, B., Fernando, S. & Hanjra, M. A. 2019 [Guidelines and regulations for fecal sludge management from on-site sanitation facilities](#). *AgEcon Search* **14**, 57. <https://doi.org/10.22004/ag.econ.296740>.
- Kabange, R. & Nkansah, A. 2019 [A review of pit latrine emptying technologies for low-income densely-populated settlements of developing countries](#). *Current Trends in Civil & Structural Engineering* **1** (2), 1–5. <https://doi.org/10.33552/CTCSE.2019.01.000510>.
- Kenya Ministry of Health 2016 *Kenya Environmental Sanitation and Hygiene Policy: 2016–2030*. Republic of Kenya Ministry of Health, Division of Environmental Health. Available from: http://sanitationandwaterforall.org/wp-content/uploads/download-manager-files/KESH%20POLICY_1.pdf
- Lozano-Gracia, N. & Garcia Lozano, M. 2018 *Haitian Cities: Actions for Today with an eye on Tomorrow (No. 122880)*. The World Bank, pp. 1–236. Available from: <http://documents.worldbank.org/curated/en/709121516634280180/Haitian-cities-actions-for-today-with-an-eye-on-tomorrow>
- Mackinnon, E., Campos, L. C., Sawant, N., Ciric, L., Parikh, P. & Bohnert, K. 2018 [Exploring exposure risk and safe management of container-based sanitation systems: a case study from Kenya](#). *Waterlines* **37** (4), 280–306. <https://doi.org/10.3362/1756-3488.00016>.
- Mara, D. 2018 [‘Top-down’ planning for scalable sustainable sanitation in high-density low-income urban areas: is it more appropriate than ‘bottom-up’ planning?](#) *Journal of Water, Sanitation and Hygiene for Development* **8** (2), 165–175. <https://doi.org/10.2166/washdev.2018.101>.
- Mazars, D. & Earwaker, P. 2019 [Improving desludging in Haiti by building the capacity of local Bayakou \(informal manual desludgers\)](#). Presented at the 36th WEDC International Conference, WEDC. Loughborough University, Nakuru, Kenya. Available from: articles/conference_contribution/Improving_desludging_in_Haiti_by_building_the_capacity_of_local_Bayakou_informal_manual_desludgers_/9587831/1
- McGranahan, G. 2015 [Realizing the right to sanitation in deprived urban communities: meeting the challenges of collective action, coproduction, affordability, and housing tenure](#). *World Development* **68**, 242–253. <https://doi.org/10.1016/j.worlddev.2014.12.008>.
- Neiburg, F. & Nicaise, N. 2011 *Garbage. Stigmatization, Commerce, Politics (Déchets. Stigmatisations, Commerces, Politiques)*. Interuniversity Institute for Research and Development, Rio de Janeiro.
- R Core Team 2020 *R: A Language and Environment for Statistical Computing (Version 22.0)*. R Foundation for statistical computing, Vienna, Austria.
- Reed, B. 2010 *Emergency Excreta Disposal Standards and Options for Haiti*. Direction Nationale de l'Eau Potable et de l'Assainissement (DINEPA) & Global WASH Cluster. Available from: <http://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/1549>
- Russel, K., Tilmans, S., Kramer, S., Sklar, R., Tillias, D. & Davis, J. 2015 [User perceptions of and willingness to pay for household container-based sanitation services: experience from Cap Haïtien, Haiti](#). *Environment & Urbanization* **27** (2), 525–540. <https://doi.org/10.1177/0956247815596522>.
- Russel, K., Hughes, K., Roach, M., Auerbach, D., Foote, A., Kramer, S. & Briceño, R. 2019 [Taking container-based sanitation to scale: opportunities and challenges](#). *Frontiers in Environmental Science* **7**. <https://doi.org/10.3389/fenvs.2019.00190>.
- Sainati, T., Zakaria, F., Locatelli, G., Sleigh, P. A. & Evans, B. 2020 [Understanding the costs of urban sanitation: towards a standard costing model](#). *Journal of Water, Sanitation and Hygiene for Development* **10** (4), 642–658. <https://doi.org/10.2166/washdev.2020.093>.
- Santiago Ortiz-Correa, J., Resende Filho, M. & Dinar, A. 2016 [Impact of access to water and sanitation services on educational attainment](#). *Water Resources and Economics* **14**, 31–43. <https://doi.org/10.1016/j.wre.2015.11.002>.
- Schrecongost, A., Pedi, D., Rosenboom, J. W., Shrestha, R. & Ban, R. 2020 [Citywide inclusive sanitation: a public service approach for reaching the urban sanitation SDGs](#). *Frontiers in Environmental Science* **8**, 19. <https://doi.org/10.3389/fenvs.2020.00019>.
- Shaw, K., Kennedy, C. & Dorea, C. C. 2021 [Non-sewered sanitation systems' global greenhouse gas emissions: balancing sustainable development goal tradeoffs to end open defecation](#). *Sustainability* **13** (21), 11884. <https://doi.org/10.3390/su132111884>.
- Shepard, J., Stevens, C. & Mikhael, G. 2017 *The World Can't Wait for Sewers: Advancing Container-Based Sanitation Businesses as a Viable Answer to the Global Sanitation Crisis*. Water and Sanitation for the Urban Poor; EY, p. 11. Available from: https://www.susana.org/_resources/documents/default/3-2756-7-1490187791.pdf
- Sklar, R. & Faustin, C. 2017 *Pit Latrines or Container Based Toilets? A Cost-Benefit Analysis Comparing Two Approaches to Improving Sanitation Access in Urban Areas of Haïti (Haiti Priorities)*. Copenhagen Consensus Center. Available from:

- https://www.pseau.org/outils/ouvrages/copenhagen_consensus_center_pit_latrines_or_container_based_toilets_a_cost_benefit_analysis_comparing_two_approaches_to_improving_sanitation_access_in_urban_areas_of_haiti_2017.pdf
- SOIL 2019 *Sanitation Safety Planning: Applying the WHO Methodology to SOIL's Operations in Northern Haiti*. Sustainable Organic Integrated Livelihoods. Available from: https://www.who.int/docs/default-source/wash-documents/sanitation-safety-planning-case-studies/haiti.pdf?sfvrsn=a055006e_4
- Spuhler, D. & Lüthi, C. 2020 Review of frameworks and tools for urban strategic sanitation planning: considering technology innovations and sustainability. *Journal of Water, Sanitation and Hygiene for Development* **10** (4), 768–785. <https://doi.org/10.2166/washdev.2020.062>.
- Tilmans, S., Russel, K., Sklar, R., Page, L., Kramer, S. & Davis, J. 2015 Container-based sanitation: assessing costs and effectiveness of excreta management in Cap Haitien, Haiti. *Environment and Urbanization* **27** (1), 89–104. <https://doi.org/10.1177/0956247815572746>.
- Tolley, E. E., Ulin, P. R., Mack, N., Robinson, E. T. & Succop, S. M. 2016 *Qualitative Methods in Public Health: A Field Guide for Applied Research*. John Wiley & Sons, Incorporated, Hoboken, United States. Available from: <http://ebookcentral.proquest.com/lib/principiacollege/detail.action?docID=4461564>
- UN Committee on Economic, Social and Cultural Rights Statement on the Right to Sanitation, Pub. L. No. E/C.12/2010/1 2010 Available from: <http://www2.ohchr.org/english/bodies/cescr/docs/statements/E-C-12-2010-1.doc>
- UN General Assembly The Human Rights to Safe Drinking Water and Sanitation, Pub. L. No. A/RES/70/169 2016 Available from: <http://docstore.ohchr.org/SelfServices/FilesHandler.ashx?enc=dtYoAzPhJ4NMj4Lu1TOebIM8c1X4GZjGEGHV9SBM9XSPnORaeC1ogH5%2BG19s5XzMWx9cuWk6oqcJ%2F%2BZodiYw%2Fv6LDHaNS4Bkv79pl5XMZnJZxsPjPhUNTznL13N8C0Cz>
- UN General Assembly Transforming Our World: The 2030 Agenda for Sustainable Development., Pub. L. No. A/RES/70/1 2015 Available from: <https://www.refworld.org/docid/57b6e3e44.html>
- UN Universal Declaration of Human Rights, Pub. L. No. Article 23 1948 Available from: <https://www.un.org/en/universal-declaration-human-rights/>
- UNICEF 2019 *Progress on Household Drinking Water, Sanitation and Hygiene 2000–2017: Special Focus on Inequalities*. World Health Organization. Available from: http://www.who.int/water_sanitation_health/publications/jmp-report-2019/en/
- USAID 2010 Haiti: Property Rights & Resource Governance. United States Agency for International Development. Retrieved from https://www.land-links.org/wp-content/uploads/2016/09/USAID_Land_Tenure_Haiti_Profile.pdf.
- VanRiper, F. 2021 *The Viability of Container-Based Sanitation as A Tool for Sanitation Coverage in Urban Haiti*. Doctoral Dissertation, Oregon State University, Corvallis, OR. OSU Scholars Archive. Available from: https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/7s75dk544.
- WHO 2018 *Burden of Disease From Inadequate Sanitation in Low- and Middle-Income Countries [Dataset]*. Available from: <https://www.who.int/data/gho/data/themes/topics/indicator-groups/indicator-group-details/GHO/burden-of-disease-from-inadequate-sanitation-in-low-and-middle-income-countries>
- WHO 2021 *Progress on Household Drinking Water, Sanitation and Hygiene 2000–2020: Five Years Into the SDGs*. World Health Organization, Geneva. Available from: <https://apps.who.int/iris/bitstream/handle/10665/345081/9789240030848-eng.pdf?sequence=1>
- WHO Joint Monitoring Programme 2017 *Sanitation Service Levels [Dataset]*. Available from: <https://washdata.org/data/household#!/dashboard/new>
- WHO/UNICEF 2017 *Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines*. World Health Organization (WHO) and the United Nations Children's Fund (UNICEF), Geneva, p. 114. Available from: https://www.unicef.org/publications/index_96611.html
- World Bank 2018 *Looking Beyond Government-Led Delivery of Water Supply and Sanitation Services: The Market Choices and Practices of Haiti's Most Vulnerable People (WASH Poverty Diagnostic)*. International Bank for Reconstruction and Development, Washington, DC. Available from: <http://hdl.handle.net/10986/28997>
- World Bank 2019 *Health, Safety and Dignity of Sanitation Workers: An Initial Assessment*. International Bank for Reconstruction and Development, Washington, DC. Available from: <https://openknowledge.worldbank.org/handle/10986/32640>
- World Bank, World Development Indicators 2018a *People Practicing Open Defecation (% of Population) [Dataset]*. Available from: <https://data.worldbank.org/indicator/SH.STA.ODFC.ZS>
- World Bank, World Development Indicators 2018b *Population Living in Slums (% of Urban Population) [Dataset]*. Available from: <https://data.worldbank.org/topic/poverty?locations=HT>

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