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Haitians' willingness to invest in rainwater infrastructure

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ABSTRACT

The use of rainwater is a reliable alternative for reducing clean water consumption and water bills. This study assessed the willingness of Haitians to invest in rainwater infrastructure (RWI). A questionnaire with closed and open-ended questions was used for this purpose. For closed-ended questions, '0' and '1' were used for negative and positive answers, respectively. Other numbers were used to encode the open-ended questions. The two-tailed *Z*-test was used to compare two proportions, where a result was statistically significant when the *p*-value was less than 0.05. Of 362 rainwater users, 81.2% used it for washing, bathing, cooking, flushing, and drinking. Approximately 73.4% of households with 1–3 people, compared with 84.0% of families with 4–6 people, used rainwater. Of all the respondents, 82.3% would invest in RWI if the government agreed to finance up to 50.0% of the project. More than 73.0% of respondents in each locality would invest in rainwater in RWI under the conditions previously mentioned. It is concluded that the implementation of RWI and decentralization of water systems would be welcomed by the rainwater users in Haiti, but the unwillingness of the Haitian government could be the main barrier to such a transition.

Key words: alternative water sources, dweller's willingness, public water system, rainwater harvesting, transition of water system, water treatment

HIGHLIGHTS

- This is the first study that assesses both users and professionals in the water supply on investment in rainwater infrastructures (RWIs).
- More than 82.3% of the rainwater users would invest in RWI.
- More than 81% of dwellers in Haiti used rainwater for washing, bathing, cooking, flushing, and drinking.
- The lack of Haitian governmental politics is the main barrier to decentralization of the water system in Haiti.

INTRODUCTION

Access to drinking water and sanitation infrastructure are among the challenges that several low-income countries face. The lack of sanitation infrastructure causes water pollution and, therefore, the spread of waterborne diseases. According to the Institute for Health Metrics and Evaluation (IHME), 3.4% (80 million Disability-Adjusted Life Years (DALY)) of global diseases are linked to inadequate water supply and sewage systems (Weidema & Fantke 2018). In Haiti, it was estimated that only 28% of the population have access to improved sanitation facilities (CIA 2018). Around 48% and 65% of rural and urban households, respectively, had access to improved water in Haiti in 2015, respectively (WHO/UNICEF 2015). Haiti is one of the world's most undeveloped countries with lower water, sanitation, and hygiene (WASH) infrastructure, which lack leads to the consumption of unsafe water (Yu *et al.* 2019) and, as a consequence, diarrhea represented 6.1% of all diseases of Haitians living in the territory (IHME 2019). The country is extremely vulnerable to natural disasters (earthquakes, floods, hurricanes, and droughts) and outbreaks (Williams *et al.* 2012). The cholera outbreak in Haiti after the 2010 earthquake confirmed the vulnerability of the country. In some isolated rural areas in Haiti, piped water systems are non-existent. If citizens do not have wells in the yards of their houses, they usually have to walk very long distances to water sources (wells, and springs or open sources) that are often contaminated by dust, flooding, mosquito larvae, and so on (Chapman *et al.* 2020), and heavy metals and fecal coliform. Most users are aware of the consequences of drinking unsafe water. Surveys conducted in Haiti demonstrated that 54% of the respondents considered water safe when treated or free of bacteria (54%), and 95% believed that they could become sick if they drank unsafe water (Rayner *et al.* 2016). They use household water treatment (HWT) methods such as adding water purification tablets, boiling, or chlorination techniques to make the water potable. About 96% of Haitians used the HWT method (Cayemittes *et al.* 2013), according to which the users add a quantity of chlorine based on their intuition. This method is used by 1.8 billion people in the world (Yang *et al.* 2012).

In 2009, the Haitian government established the Directorate of Potable Water and Sanitation (DINEPA) with the purpose of reforming, regulating, and developing the country's WASH. The effective distribution of water represents a challenge due to the centralized water system being used and controlled by a determined group (state representative) in each locality. The distribution is generally made according to a schedule, every 3 days or weekly, depending on the locality. Users sometimes complain that the water is either salty, dirty, or has too much chlorine. When the network has a technical problem, it can take several days or even months to fix it. Such a situation obliges residents to buy water from their neighbors who possess water reservoirs. The price of water buckets varies depending on the duration of the problem and the locality. Those who live in mountain areas often have difficulties receiving piped water at home due to the lack of pressure in the pumps caused by other users tapping illegally into the same Polyvinyl Chloride (PVC) pipes.

In Haiti, the population generally uses primitive means (e.g., jerry cans, buckets, and plastic drums) to collect rainwater for household activities such as washing dishes and clothes, flushing, and bathing. Rainwater infrastructure (RWI) could be a relevant alternative for increasing access to improved water and prevent stormwater overflows and erosion in Haiti, as well as other countries. In Taiwan, the use of rainwater harvesting systems (RWHSs) facilitates domestic water-use savings and energy savings, estimated at 21.6% and 138.6 (kWh/year-family), respectively (Chiu *et al.* 2015). Studies carried out in different localities, such as China by Zhu *et al.* (2004), Nigeria by Efe (2006), Austin, USA, by Mendez *et al.* (2011) and Seoul by Lee *et al.* (2012) have confirmed that rainwater collected from metallic roofs meets all or almost all the World Health Organization standards for drinking purposes. Rainwater is generally non-polluted if its quality is not contaminated by dirt, organic micropollutants, metals, pesticides, etc. (Meera & Ahammed 2006).

In terms of microbial quality, rainwater can be altered by the excreta of animals (e.g., birds, rodents) that are sometimes found on roofs (Ahmed *et al.* 2011). Other factors, like roof material, physical boundary conditions, location, precipitation event characteristics, local meteorological factors, chemical properties, and so on, are also likely to influence rainwater quality (Forster 1998). However, simple systems to dodge the first flush (1–2 mm of rain) are enough to clean the roof and only the fraction of the water for drinking needs to be filtered and disinfected before use (Hora *et al.* 2017). This is a popular practice in Australia and in the Brazilian semi-arid where 1 million systems were installed in one decade. Studies have shown that the system is suitable for many kinds of regions, including for rainy areas. The RWHS offers safe water with low energy consumption. It may reduce floods in urban areas. Despite a lack of technical knowledge, this practice is still used as an emergency solution or in places where there is no other conventional source of water, such as wells or public service. Water collected from rivers, wells, and other sources may be deteriorated by total dissolved solids (TDS), calcium, and sulfate due to the interaction effects between groundwater and geological formations (Baazi *et al.* 2020). Consequently, it may be concluded that this water is not good for public consumption and does not respect the limits for physical and chemical parameters (e.g., pH, conductivity, and TDS), chemical properties related to water treatment, and hardness fixed by the WHO.

To benefit from the advantages offered by rainwater, an understanding of public perception is required to stimulate stakeholders to improve public water systems or seek other options, such as the democratization of water systems. This option may also lead to the decentralization of the water system currently used, and a reduction in water bills. However, the willingness of people to act may vary from one community to the next, or even in the same locality, due to the different demographic factors (financial means, age, study level, household size, and monthly salaries) that might exist. Haiti, with its high discrepancies in terms of income, study levels, and access to water is an example of such a reality. To the best of our knowledge, no previous research has been conducted on this subject in Haiti. Therefore, this present study intends to assess the willingness of Haitians to invest in an RWI. Since socio-demographic aspects play an important role in the acceptance of new technologies, we hypothesize that: (i) the utilization of rainwater is common in Haiti; (ii) dwellers would accept investing in RWI; and (iii) the willingness to invest in RWI varies according to the socio-demographic aspects of the respondents.

Our research paper proceeds as follows: In the second section, we present the research methodology, which includes the study area, survey design, inclusion criteria, validity of the questionnaire, and distribution of the questionnaires. The third section covers only statistical analysis. The fourth section envelops the results and discussion. In the fifth section, we seek to understand whether dwellers are willing to invest at least fifty percent of the RWI cost. In the sixth section, we address the waterboard employees' willingness to invest in RWI. In the final section, we present the conclusion and provide some recommendations, and limitations of this research to help decision-makers understand the need to invest in RWI. We expect that financial resources will be the major concern for the respondents when deciding whether to invest in rainwater infrastructure. Since the water supply is not legally distributed in the country, we expect that dwellers in arid areas are more willing to invest in RWI than others.

METHODOLOGY

Study area

Haiti is a Caribbean country that has approximately 12 million inhabitants. According to the International Monetary Fund, the Gross Domestic Product (GDP) per capita income of Haiti was estimated to be 857 USD in 2018. The total area of Haiti is 27.750 km^2. More than 75.0% of this area is rough and mountainous (MDE 2001). The temperature varies from the plains to the mountains, with mean averages of 27 and 16 °C, respectively. Haiti's climate is considered tropical. The annual rainfall varies between the low and high altitudes, from 400 to 2,000 mm, respectively (MDE 1999). Access to drinking water is precarious in Haiti. The main ways of supplying water for drinking and domestic use are wells or rivers (35%), public fountains (21%), and the purchase of water buckets (19%) (Saade 2005). For example, in the rural areas of Caracol and Limonade, wells, rivers, and fountains are the main water supply means used by the local populations, estimated at 4.440 and 11.059 residents, respectively (MEF/IHSI 2015). Different means of water supply, such as purchasing water trucks and water buckets, a public water system, among others, are used in the urban areas of Delmas, Cap-Haitien, Fort-Liberte, and Port-au-Paix, which have urban populations estimated at 395.260, 170.994, 22.416, and 121.220 inhabitants, respectively (MEF/IHSI 2015). However, millions of cubic meters of rainwater are lost annually and cause floods almost every year. Natural hazards such as erosion, river sedimentation, flooding, and drought often affect Haiti due to its localization, lack of infrastructure, and anthropogenic actions such as accelerated deforestation, over the last 50 years. Improved water is unevenly distributed from urban to rural areas. Furthermore, Haitian government agencies do not have enough resources (including professionals) to address the problem of drinking water in the country (Gelting *et al.* 2013).

Survey design

Two questionnaires, written in Haitian Creole, about investment in infrastructure for rainwater collection were used for face-to-face interviews with inhabitants in two rural areas (Caracol and Limonade) and five urban localities (Delmas, Port-de-Paix, Fort-Liberté, Cap-Haitien, and Fort-National (a shanty town) in different geographical departments of Haiti (Figure 1) about the investment in infrastructure for rainwater collection. The first questionnaire was divided into four sections with closed and open-ended questions. The first section covered the socio-demographic aspects of the respondents (e.g., gender, age, study level, religion, monthly income, and household size). The second section encompassed the following information: connection to a public water network, water bill payment, public water quality, purpose of the use of public water, information about public water treatment before use, information about having tap water at home, and tap water quality. The third section referred to the habit of using rainwater, treatment and storage methods, rainwater quality and purpose of use, storage duration, and finally, a comparison between rainwater and other water sources. In the fourth section, we focused on questions linked to water towers, placing or building it on the top of their houses, the kind of water stored in the water tower, and the willingness to invest in RWI. The second questionnaire aimed to collect information from the employees of the public water system about the water provided, the origin of the water, problems faced in improving the service, and the willingness of the Haitian government to support RWI.

Inclusion criteria and validity of the questionnaire

The criteria included dwellers that had lived in the localities for at least 6 months, were at least 18 years old (male or female), were neither decision-makers nor planners involved in water supply, and were willing to answer the questions. The validation criteria of a questionnaire require that it be correctly filled out, with no crossed-out answers. Regarding closed questions (e.g., 'yes', 'no', 'I do not know'), only one answer was acceptable. The valid questionnaires were signed either by the respondent or by someone from his or her family. Each questionnaire with no signature was rejected.

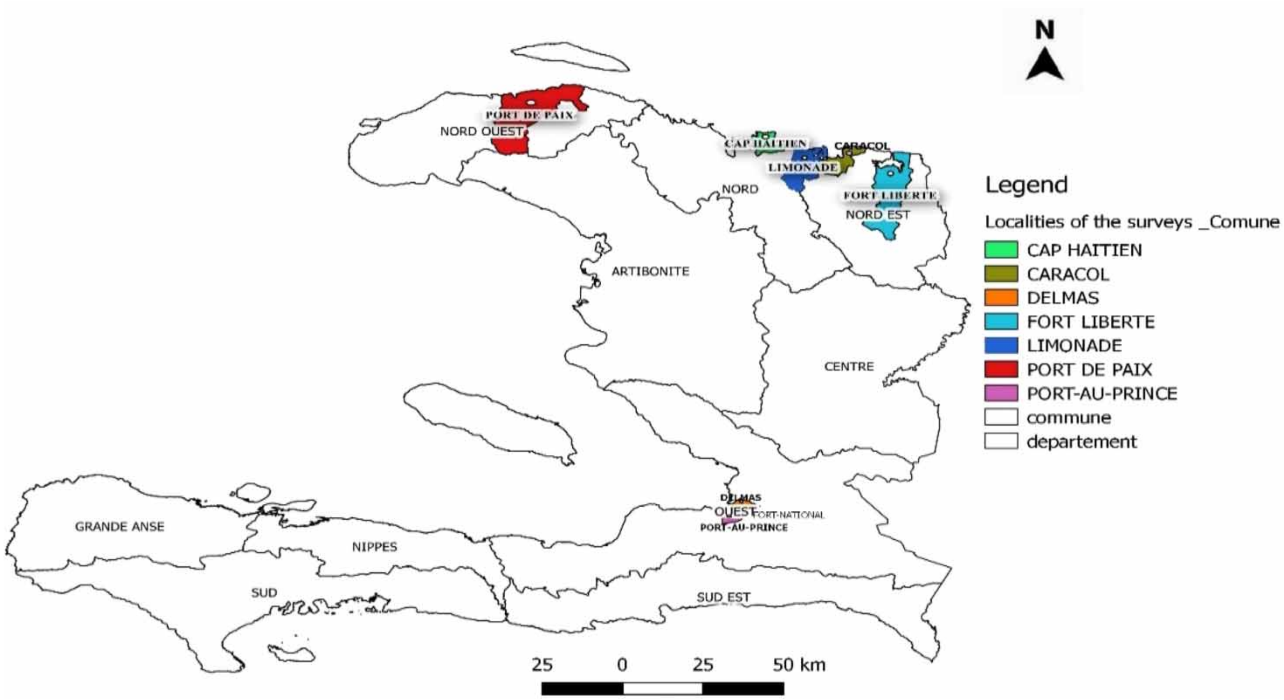

Figure 1 | Map of the localities of the surveys.

Distribution of the questionnaires

From August to September 2020, 394 participants living in seven municipalities were interviewed in Haiti. According to our pre-established validation criteria, 362 (91.9%) were valid for the statistical analysis (Table 1). In addition, six (6) employees working for DINEPA were interviewed.

Statistical analyses

The data were registered in the Microsoft Office Excel spreadsheet and then exported to R software (Version 3.4.3) to perform the statistical analysis. The analysis was done in parts. For the closed-ended questions, a binary system referred to as '0' and '1' was used for negative and positive answers, respectively. Other numbers were used to encode the open-ended questions. The two-tailed Z-test was used to compare the two proportions. Each result was statistically significant when the p-value was less than 0.05.

RESULTS AND DISCUSSION

The results showed that most of the respondents practiced the Catholic religion (57.5%), 61.3% were female, 28.7% ranged from 26 to 35 years old, and 33.7% had a study level between incomplete high school and completed high school (Table 2).

Sources of water used in Haiti and the perceptions of the users

Public water in this study refers to the water provided by DINEPA. Only 54.0% of all the interviewees were connected to a public water network. A further 43.5% thought this water was good quality, and 32.5% had tap water in their houses. The

Table 1 | Distribution of the sample

Communes	Fort-National	Delmas	Cap-Haitien	Port-de-Paix	Caracol	Limonade	Fort-Liberté	Total
Applied quest*	30	20	100	42	57	108	37	394
Valid quest*	27	17	93	37	51	103	34	362
Valid R*. R*(%)	90.0	85.0	93.0	88.1	89.5	95.4	91.9	91.9

Note: quest*, Questionnaires; R*. R*, Recovery Rates.

Table 2 | Socio-demographic characteristics of the respondents

Socio-characteristics		Numbers	Proportion (%)	Description
Gender ($n = 362$)	Male	140	38.7	1
	Female	222	61.3	2
Household size	1–3	94	26	1
	4–6	268	74	2
Age range	18–25	69	19.1	1
	26–35	104	28.7	2
	36–45	88	24.3	3
	46–60	85	23.5	4
	61+	16	4.4	5
Study level	Illiterate	2	0.6	0
	IF-CF	105	29.0	2
	IS-CS	122	33.7	4
	IB-CB	112	30.9	6
	Others	21	5.8	7
Monthly salaries (USD)	Up to 83.3	154	44.8	1
	83.3–167	82	23.8	2
	167–250	30	8.7	3
	250 or more	78	22.7	4

Note: IF-CF, Incomplete elementary–completed elementary; IS-CS, incomplete high school–completed high school; IB-CB, Incomplete bachelor degree–completed bachelor degree; others: more than bachelor degree. Due to the lack of data, the monthly salaries of residents in Fort-National are not included in this table.

other participants affirmed that the water was dirty and salty. The salinity of the water could be due to the presence of salts such as Magnesium Sulfate, Sodium Hydroxide, Sodium Chloride, Ammonium, and Potassium Nitrate in the sources where it is collected (Obianyo 2019). The residents had tap water connected either to the public water system or to their own water system treated by inverse osmosis, or both. In Caracol, Fort-Liberté, and Port-de-Paix, 90.0, 97.1, and 91.9% of the participants are connected to a public water system, respectively. Concerning water quality, the result of this study is slightly superior to that found by Shalamzari *et al.* (2016), in which 41.4% of the residents were satisfied with the quality of the water they used.

In one study conducted in France, 5.0% and 8.0% of the respondents were worried about the potability of rainwater and doubted its quality, respectively (Seidl *et al.* 2010). In this present study, 81.2% (52.5% female as opposed to 28.7% for men) of all the respondents used rainwater in their houses, and 49.5% of them treated it for bathing, washing clothes, cooking, etc. They utilized gallon drums, plastic water barrels, buckets, reservoirs, and water towers to collect rainwater. Previous research carried out in the locality of Legane indicated that 72.1% of the participants treated the public water before drinking it (Galada *et al.* 2014). In the localities of this study, the percentage of dwellers that used rainwater ranged from 64.7 to 100% (Figure 2). The rainwater use varied from rural to urban areas. Though the respondents held positive views of the water patterns, it is observed that the majority of users use rainwater as a water source. Caracol and Limonade (two rural areas) exhibited the lowest percentages (64.7 and 77.7%). However, in urban areas, this practice fluctuated from 81.1 to 100%. In contrast to a study carried out in Zambia in which the use of rainwater was rejected due to having no priority in people's culture and social context (Handia *et al.* 2003), in this study, the main concern was associated with the deterioration of rainwater quality, particularly the generation of certain aquatic bugs after a few days of storage. Some participants argued that the rainwater is 'slippery' and difficult to rinse off the body. They also reported that it darkens skin and causes itching when used for bathing. This deterioration may happen due to bird droppings, organic matter, debris on the roof where the rainwater is collected, uncleanliness of the gutter, debris in the storage tanks, or if the storage tanks are not well covered.

In Caracol, Limonade, and Cap-Haitien, rainwater is treated by 48.6, 36.1, and 33.7% of the users, respectively (Figure 3). The residents of Port-de-Paix, Fort-Liberté, and Caracol pay an average water bills estimated at 21.8, 3.8, and 3.9 USD per month, respectively. Port-de-Paix exhibited the highest water bills as the payment is per volume consumed (0.63 USD/m^3). This average tariff is higher than that of Malaysia (0.39 USD/m^3) but lower than those of Indonesia and Singapore, which

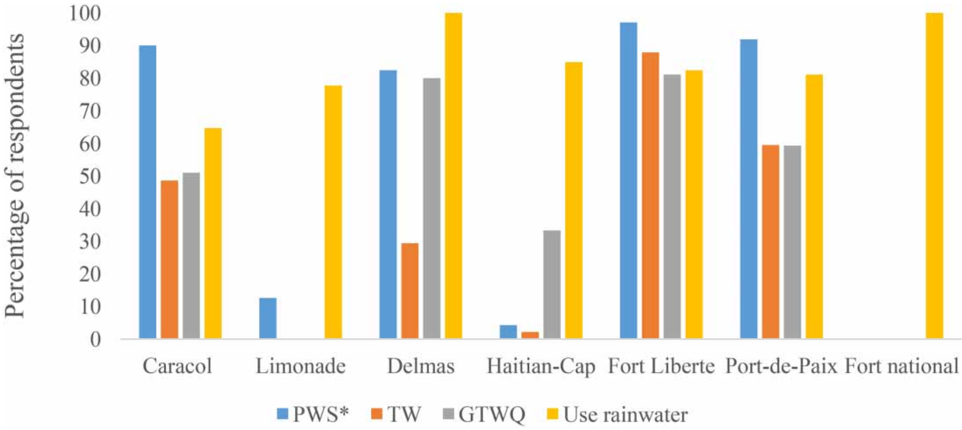

Figure 2 | Different types of water used in the localities. *Note:* PWS, public water system near to their houses; TW, tap water at home; GTWQ, tap water quality is good.

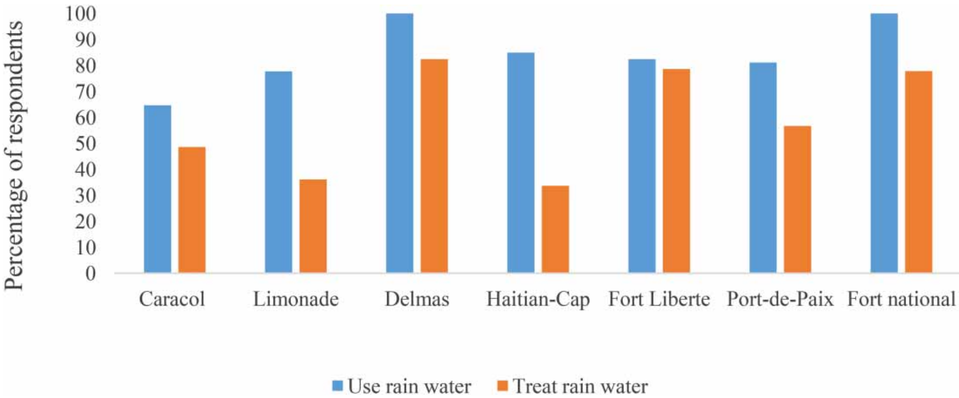

Figure 3 | Rainwater used and rainwater treated by the inhabitants.

are 0.77 and 1.88 USD/m^3, respectively (Lee *et al.* 2016). Even though centralized water systems offer benefits such as improved public health, environmental protection, economy of scale, and so on (Galada *et al.* 2014), decentralized water systems seem to be better for developing countries like Haiti, where most of the population have small enterprises or are unemployed. A decentralized water system could be an economical way to mitigate high water demand, high pressure on the hydrological cycle, climate change (Shalamzari *et al.* 2016), as well as water scarcity. The use of rainwater is a reliable alternative to dealing with potable water issues, water stress and water bills in Haiti. The RWHS can play a role in the management of rainwater runoff and water supply (Araujo *et al.* 2021). It has a cost-effectiveness advantage and does not require very highly skilled labor for its maintenance.

All dwellers in Fort-National and Delmas use rainwater. The absence of a public water system in Fort-National may explain the high use of rainwater. For the localities, rainwater treatment varies from 56.7% for Port-de-Paix to 82.4% for Delmas (Figure 3). The techniques used for rainwater treatment in Haiti are chlorine, water purification tablets, boiling, and adding salt or lemon. Few respondents affirmed that they have water filters. Insufficient space for rainwater storage is a factor leading non-users to reject rainwater alternatives. This observation is consistent with research carried out in Iran by Shalamzari *et al.* (2016) and Sheikh (2020) and in Africa by Campisano *et al.* (2017). More than 70.0% of the participants used rainwater. Generally, 92.6, 40.5, 39.5, 31.4, and 19.9% of them used it for washing, bathing, cooking, flushing, and drinking purposes, respectively (Figure 4). These results are similar to findings of research conducted in Australia, where it is common to use rainwater in urban households for drinking and cooking purposes, sometimes without disinfection treatment (Gardner & Vieritz 2010). Over the 6 years up to 2013, home rainwater use increased from 15 to 28% in Australia (Sharma & Gardner 2020).

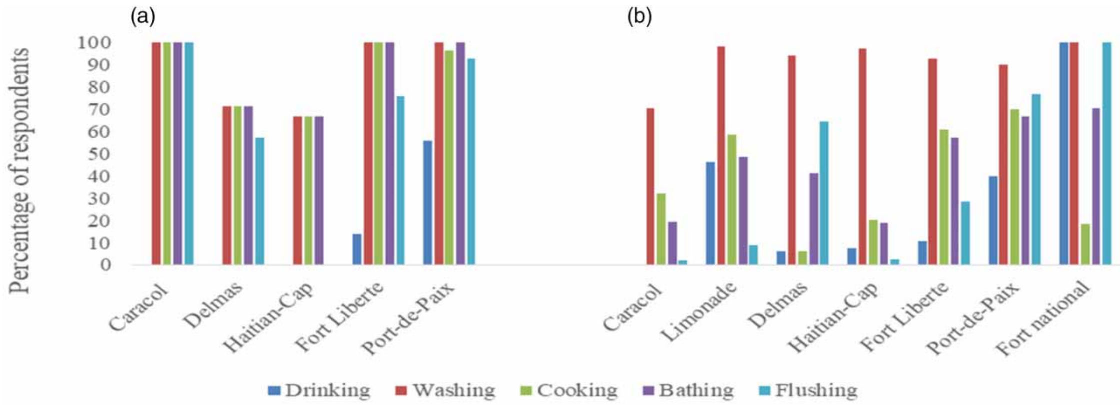

Figure 4 | Purposes of using main water at home (a) and rainwater (b) in Haiti.

The residents had a more positive attitude toward rainwater than toward public water for drinking. At least 90% of the participants from Port-de-Paix, Fort-Liberté, Cap-Haitien, Delmas, and Limonade used rainwater for drinking (Figure 4). Caracol had the lowest percentage of rainwater users for drinking purposes, due to most of them having artesian wells or shallow wells in the yards of their houses. Regarding public water systems, over 96.6% of dwellers in Caracol, Fort-Liberté, and Port-de-Paix, use this water only for washing clothes, cooking, and bathing (Figure 4(a)). There are people in rural areas that use water for flushing because of a lack of WC. A total of 6.0 out of 7.0 localities used rainwater. This water is more in demand for drinking purposes than the water provided by DINEPA. 55.6% represented the highest percentage of participants that utilized public water for drinking (Figure 4(a)). This proportion is inferior to the finding of research conducted in Salomon Island, in which 98.0, 89.0, and 72.0% of the respondents used public water sources for drinking, cooking, and bathing, respectively (Anthonj *et al.* 2019).

The drinking purpose had the lowest percentage of using rainwater in the localities (Figure 4(b)). The availability of other water sources may lead residents to consider rainwater only for non-consumption purposes (Mukaromah 2020). Females liked to use rainwater for washing clothes because it generates more moss, and therefore they use fewer detergents. Most females used rainwater for drinking and bathing purposes more than men did. For drinking, a significant difference between the genders was found only in the locality of Port-de-Paix (p-value $= 0.02$). Whereas in Cap-Haitien (p-value $= 0.04$), and in Limonade (p-value $= 0.01$) a statistically significant difference for bathing was found.

Comparison of rainwater to other sources of water

Dwellers of Caracol (39.3%), Limonade (48.1%), Cap-Haitien (53.2%), and Fort-National (74.1%) thought rainwater had good quality and, therefore, preferred to use it to other water sources (Figure 5). Residents of the other localities believed that the

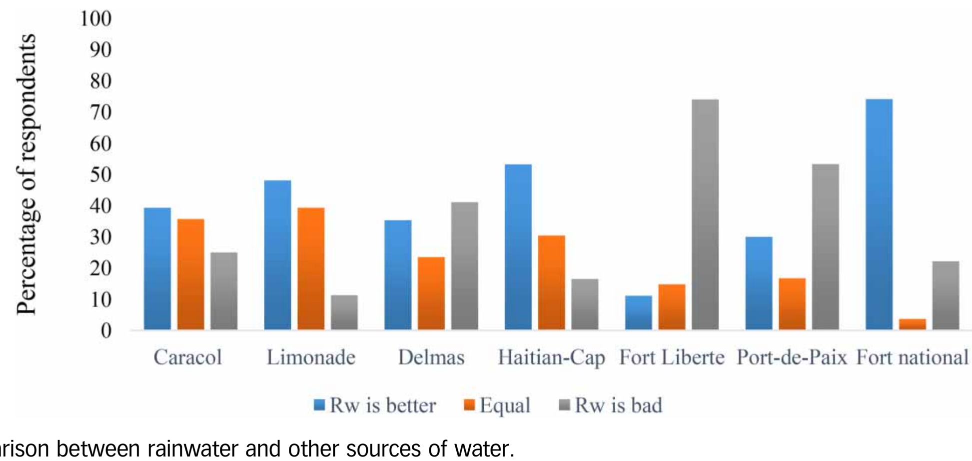

Figure 5 | Comparison between rainwater and other sources of water.

rainwater quality was not good. Social interactions and socio-demographics are factors used to assess residents' perceptions and know how to reduce water scarcity (Rasoulkhani *et al.* 2018).

When comparing rainwater to other water sources from one locality to another, such as Caracol and Fort-Liberté, Caracol and Fort-National, Limonade and Fort-Liberté, Limonade and Fort-National, Cap-Haitien and Fort-Liberté, Cap-Haitien and Port-de-Paix, Delmas and Fort-National, it was found that the p-value ranged from 0.0001 to 0.030. The rainwater quality is equal to other water sources. Significant differences were identified between Caracol and Limonade, Caracol and Port-de-Paix, Caracol and Fort-National, Limonade and Cap-Haitien, Delmas and Fort-National, Cap-Haitien and Fort-National. The lowest Z-score and p-value were 2.017 and 0.00001, and the high values were 8.48 and 0.003. The test gave the highest value, but the significance is minor. On one hand, these results explain how the perception of rainwater users varies between localities, and, on the other hand, shows the need to use alternative water sources. In Port-de-Paix, females represented the highest proportion of rainwater users compared to males (Figure 6). It may be because they generally stay at home. They use more water than men and, therefore, know more about water quality. Gender did not influence the use of rainwater, except in Cap-Haitien. Females represented the highest proportion of rainwater users.

Generally, 23.3 and 10.7% of females used rainwater for bathing and drinking, respectively, as opposed to 17.2 and 8.7% of men. In one research carried out in Brazil, 25.0% of males accepted using rainwater for drinking (Seidl *et al.* 2010). Contrary to a study carried out in China by He *et al.* (2007), education level did not influence the respondents' habit of using rainwater. Regarding interviewees' ages, rainwater was used by over 74%, except for those living in the locality of Caracol (17.0%) (Figure 7).

The interviewees aged 18–25, 26–35, 46–60, and 61 or more years old represented 81.7, 83.0, 72.8, 77.0, and 66.2% of participants that used rainwater, respectively (Figure 7). It can be seen that the younger respondents had higher proportions.

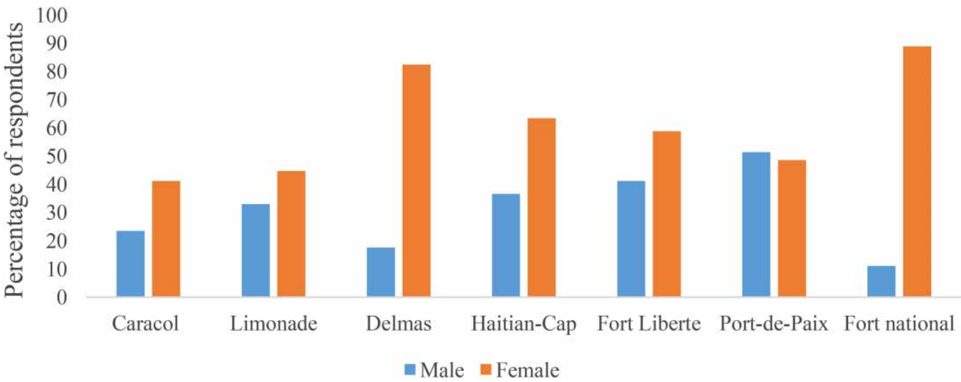

Figure 6 | Use of rainwater versus gender in the different areas of the studies.

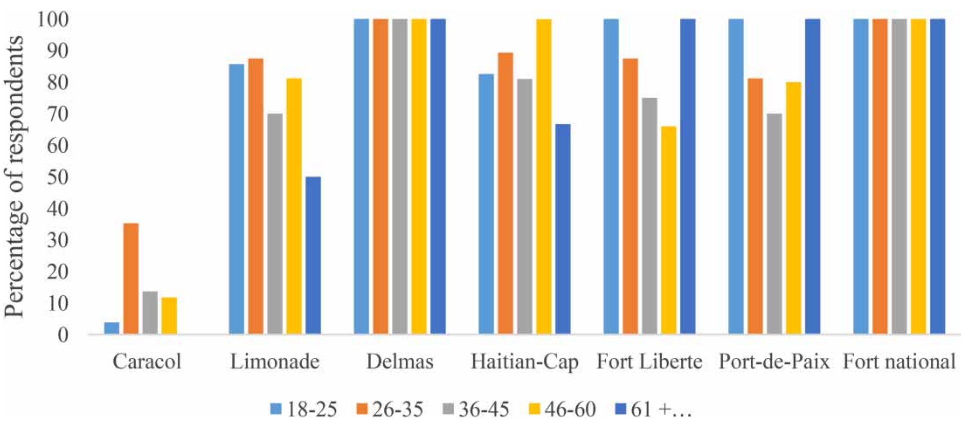

Figure 7 | Age range of the respondents in relation to willingness to use rainwater.

Financial resources determine the inhabitants' habits of using rainwater. Low-income dwellers (up to 83.3 USD monthly) were the major users of rainwater (36.3%) (Figure 8).

Approximately 6.1% of the respondents earning 167–250 USD had the habit of using rainwater in their daily activities. Rainwater use among those who had a monthly salary estimated at 83.3 to 167 USD and 250 USD or more was only 19.2 and 18.6%, respectively (Figure 8). There is no significant difference between the different proportions. The respondents that had the lowest monthly salaries represented 45.3%. The households with more people had a better acceptance of rainwater in the localities of this study, except in Port-de-Paix, where households with 1 to 3 people represented a higher proportion (83.3%) than those with 4–6 people (80.6%) (Table 3). There is no significant difference between the two groups of households.

From all participants, 73.4% of 1–3 people households had a rainwater user, in opposition to 84.0% for households with 4 to 6 people. These high acceptance rates indicate that rainwater could be used in place of water from wells and fountains that is contaminated due to the lack of sanitation infrastructure in the country. It is observed that large households are more willing to use rainwater than small households, but the difference is not statistically significant. This could be explained by the fact that large households use more water or spend more money on buying clean water. This result is consistent with research

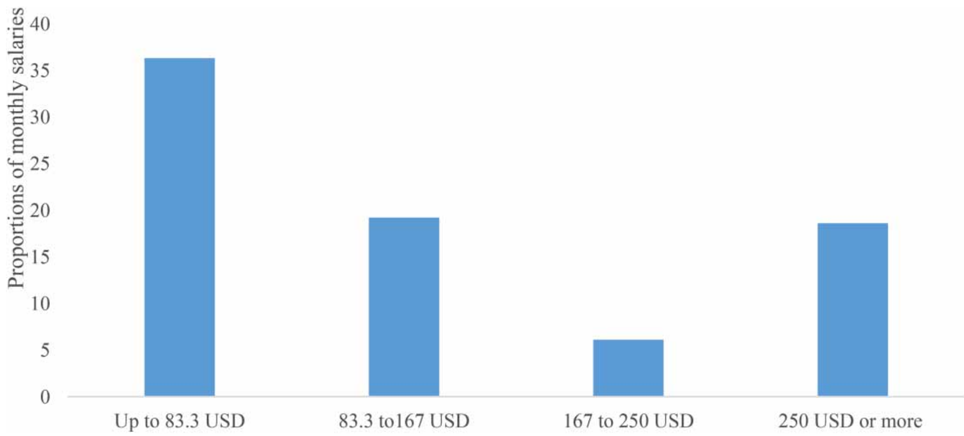

Figure 8 | The practice of using rainwater according to the monthly salaries of the inhabitants. *Note*: The data of Fort-National were not represented in the calculus displayed in the figure due to the lack of willingness of the respondents to respond the question referred to their monthly salaries.

Table 3 | The use of rainwater according to the household size of the respondents

Localities	People/Household	Number	Proportion (%)	User of rainwater	User of rainwater (%)	Two-tailed test (*p*-value)
Caracol ($n = 51$)	1–3	26	51.0	16	61.5	0.6
	4–6	25	49.0	17	68.0	
Limonade ($n = 103$)	1–3	19	18.4	12	63.2	0.09
	4–6	84	81.6	68	81.0	
Delmas ($n = 17$)	1–3	8	47.1	8	100.0	ns
	4–6	9	52.9	9	100.0	
Cap-Haitien ($n = 93$)	1–3	19	20.4	14	73.7	0.12
	4–6	74	79.6	65	87.8	
Fort-Liberté ($n = 44$)	1–3	4	9.1	2	50.0	0.55
	4–6	40	90.9	26	86.7	
Port-de-Paix ($n = 37$)	1–3	6	16.2	5	83.3	0.97
	4–6	31	83.8	25	80.6	
Fort-National ($n = 27$)	1–3	12	44.4	12	100.0	ns
	4–6	15	55.6	15	100.0	

Note: ns, not statistically significant.

carried out by Staddon *et al.* (2018), in which the adoption of rainwater is higher in large families than in small families. It is also in accordance with findings of research conducted in the state of Guanajuato, central Mexico, which demonstrated that rainwater was the main water source (Fuentes-Galván *et al.* 2018). In Tlalpan, Mexico, rainwater is capable of meeting 88% of household water demand during the 6-month wet season, with an annual saving of 55% (Nolan & Lartigue 2017). In Brazil, the use of rainwater has a high potential for potable water savings and an economic benefit for public administration due to a reduction in water bills (Ghisi *et al.* 2017), and leads to potential potable water savings estimated at 41% in the Southeastern part of the country (Ghisi *et al.* 2007).

Rainwater utilization can also be used for drinking purposes in countries that face a potable water problem, such as Haiti. Studies conducted in Australia demonstrated that trace metals such as arsenic, cadmium, chromium, lead and iron in rainwater were below the health limit guidelines, except in some industrial areas (Chubaka *et al.* 2018). According to the results of research conducted in Jalisco state, Mexico, the introduction of RWHSs in this community significantly decreased the incidence of Acute Diarrheal Diseases significantly (González-Padrón *et al.* 2019).

Dwellers' willingness to invest in RWI

The highest percentage of residents that had a water tower in each locality did not exceed 29.4%. We found that all the participants had a water tower only in the locality of Caracol. More than 73.0% of respondents in each locality would invest in RWI if the government or other decision-makers invest at least 50.0% (Figure 9). Of 362 users of rainwater, 82.3% would invest in RWI under the same conditions previously mentioned.

This high acceptance proves that the democratization and decentralization of the water system in Haiti is possible. Each resident, or the majority of them, could have their own water system. A lack of financial resources was the major obstacle for the remaining 17.7%. Some respondents commented that they were not landlords of the houses; therefore, they were reluctant to invest in such a project. Research implemented in Mexico revealed that water storage tanks cost more than half of the total cost required to implement rainwater harvesting and greywater reuse systems (Zavala *et al.* 2016). In this study, the willingness of the inhabitants to invest in RWI varied from rural dwellers to urban dwellers. About 87% of dwellers in urban areas, as opposed to 73.3% of inhabitants living in rural areas, use rainwater for household activities. A significant difference was found between the two groups (Z-score $= 3.2856$, p-value $= 0.001$, 0.05). This result is consistent with the results of research conducted in the Philippines, in which 98.2% of the respondents wanted to use an RWHS for their domestic water source, 89% were willing to pay for collected water, and 94% were interested in having their own private RWHS (Roa *et al.* 2019). In our present work, the inhabitants of rural areas are less interested in using rainwater. This may be because they have other water sources, like springs and wells in their yards. It also found that dwellers in urban areas were more willing to invest in RWI than those in rural areas (87.5% of inhabitants in urban areas, as opposed to 75.3% of those who dwelled in rural areas). This result is statistically significant. Among the socio-demographic aspects considered (e.g., gender, study levels, age, and income), gender was not a factor that influenced the attitude and willingness in both rural and urban areas to invest in RWI. In the rural areas, the only significant difference was found in the income aspect between those (68% of respondents) that have a monthly salary estimated at up to 83.3 USD and those (86.5% of the

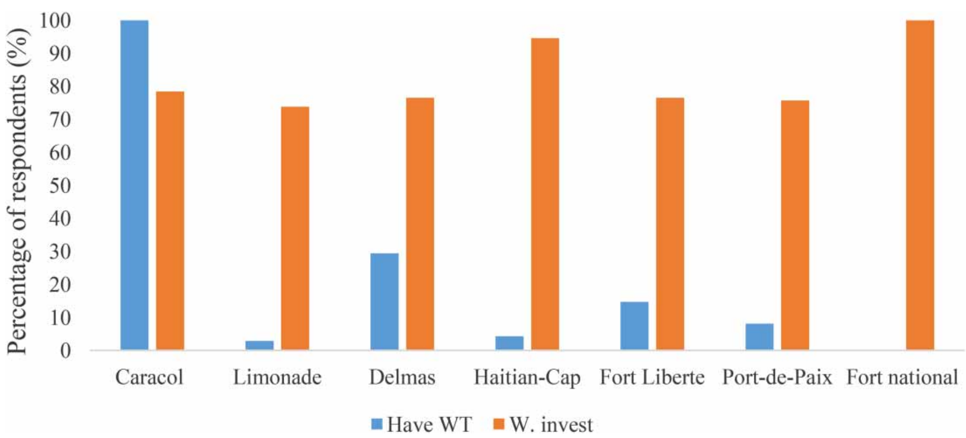

Figure 9 | Respondents that had water tower and would invest in RWI.

interviewees) with an estimated monthly salary equivalent to 250 USD or more. However, in urban areas, significant differences were found between those who were 18–25 years old compared to those who were 36–45 years old, and 18–25 years old compared to those who were between 46 and 60 (with p-values varying from 0.014 to 0.027). Regarding their incomes, a significant result (p-value = 0.004, 0.05) was found between those that gained up to 83.3 USD and those who received 167–250 USD monthly as a salary. In urban areas, this study did not identify the education level of the dwellers as a main factor in investing in RWI. We observed that the socio-demographic aspects referring to household size, age, and gender influenced the attitude toward and willingness of the residents toward the use of rainwater, where the largest households (i.e., households with 4–6 people), and females, represented statistically significant results compared to small households and males, respectively. In the age category, a statistically significant difference was found between residents aged 26–35 years old and those aged 36–45 years old, in which the youngest residents were more willing to use rainwater. No significant results were found among socio-demographic aspects of the residents regarding their attitude towards and willingness to invest in RWI.

Employees' willingness to invest in RWI

A total of six (6) employees at DINEPA (3 directors, 1 assistant director, 1 senior engineer, and 1 tracking engineer) were interviewed. They are all civil engineers and work in the areas of this study. Three (3) employees said that the water they distributed was from wells. The other three distributed water from catchment areas. When questioned about the frequency of distributed water, half of them affirmed that the distribution frequency varied from 3 to 5 days and argued that lack of energy was the main issue. The others said that there was no problem. However, they recognized that water distribution frequency varied from one to three days. Concerning the possible willingness of the Haitian government to finance at least 50% of RWI costs, 5 out of 6 had a positive view that investment in RWI is a promising option, but all responded that the government would not be interested in such a project. This finding indicates that the Haitian government could be the main barrier to the implementation of RWI in the country.

Economic aspects and local regulations can be considered as the main constraints to implementing RWH systems and technology selection (Campisano *et al.* 2017). Contrary to research findings in the Philippines, in which initiatives for implementation of rainwater solutions is socially and politically encouraged (Esguerra *et al.* 2011), in this present research, the lack of resources and the unwillingness of the Haitian government are the main impediments. Some of the respondents highlighted that water catchment from wells would be less expensive, and therefore, more economical for the decision-makers. Even with the high percentage of rainwater users and their eagerness to invest in RWI, the unwillingness of the government to invest in such an alternative is the main barrier. This observation is in accordance with research conducted by Kumar (2004), in which the authorities did not have the desire to invest in roof water harvesting.

CONCLUSIONS, STRENGTHS AND LIMITATIONS, AND RECOMMENDATIONS

This study assessed the willingness of Haitians to invest in RWIs. More than half of the respondents had public water near their houses. However, only 43.5% of them thought this water was a good quality. Around 81.2% of all the respondents used rainwater, and 49.5% treated it before use. Rainwater is used in Haiti for washing, taking showers, cooking, flushing, and drinking purposes. Around 44.9% of the rainwater users thought this water was better than other water sources, 19.9% thought it was equal to other water sources, and 35.0% thought it was. However, only 0.1% affirmed that rainwater was the worst source. Socio-demographic aspects such as gender, age, monthly salaries, and study levels did not statistically influence the willingness to use rainwater. Large household sizes were more willing than small household sizes to invest in RWIs. 82.3% of respondents affirmed they would invest in RWI if the government accepted to finance 50% or more of such a project. All the employees at DINEPA thought and affirmed that investing in RWI was a reliable alternative. However, they all argued that the Haitian government would not invest in such a project. Therefore, it was concluded that the decentralization or democratization of water systems is seen as a positive development among the different localities targeted in this study, but the unwillingness of the government could be the main barrier. It can also be concluded that rainwater is important for the residents of Haiti and a major part of them already know how to treat it. As such, our two first hypotheses were verified. The last one was not verified, as the socio-demographic aspects did not influence the attitude and willingness of the residents to invest in RWI. One of the strengths of this study is that it encompasses the attitudes of residents from different localities in regions of Haiti concerning the public water system, rainwater, and the possibility of investing in RWI. However, the limitations of this study include small interviewee numbers in some localities compared to others, and the unwillingness of some respondents to provide information about their incomes. Lack of information about whether or not residents would prefer to have a town expert to maintain their rainwater system, and the possibility of changing their opinion if power reliability was improved, are also among the main limitations of this study. Further research in other localities and interviewing more inhabitants is necessary to find out the willingness of more rainwater users to invest in such technology in the country, which in turn can help decision-makers understand the need for the implementation of rainwater infrastructure.Electricity supply improvement is an important aspect of the acceptance of RWI. However, no studies have yet addressed this issue in Haiti. Information about whether residents would prefer a town expert to maintain RWI is also an important point that is strongly encouraged to address the attitude and willingness of residents to invest in RWI.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

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

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