MAY 2020

Scaling Up Rainwater Harvesting to Address Water Shortages in Mexico City

Mexico City Government,
Municipality of Benito Juarez

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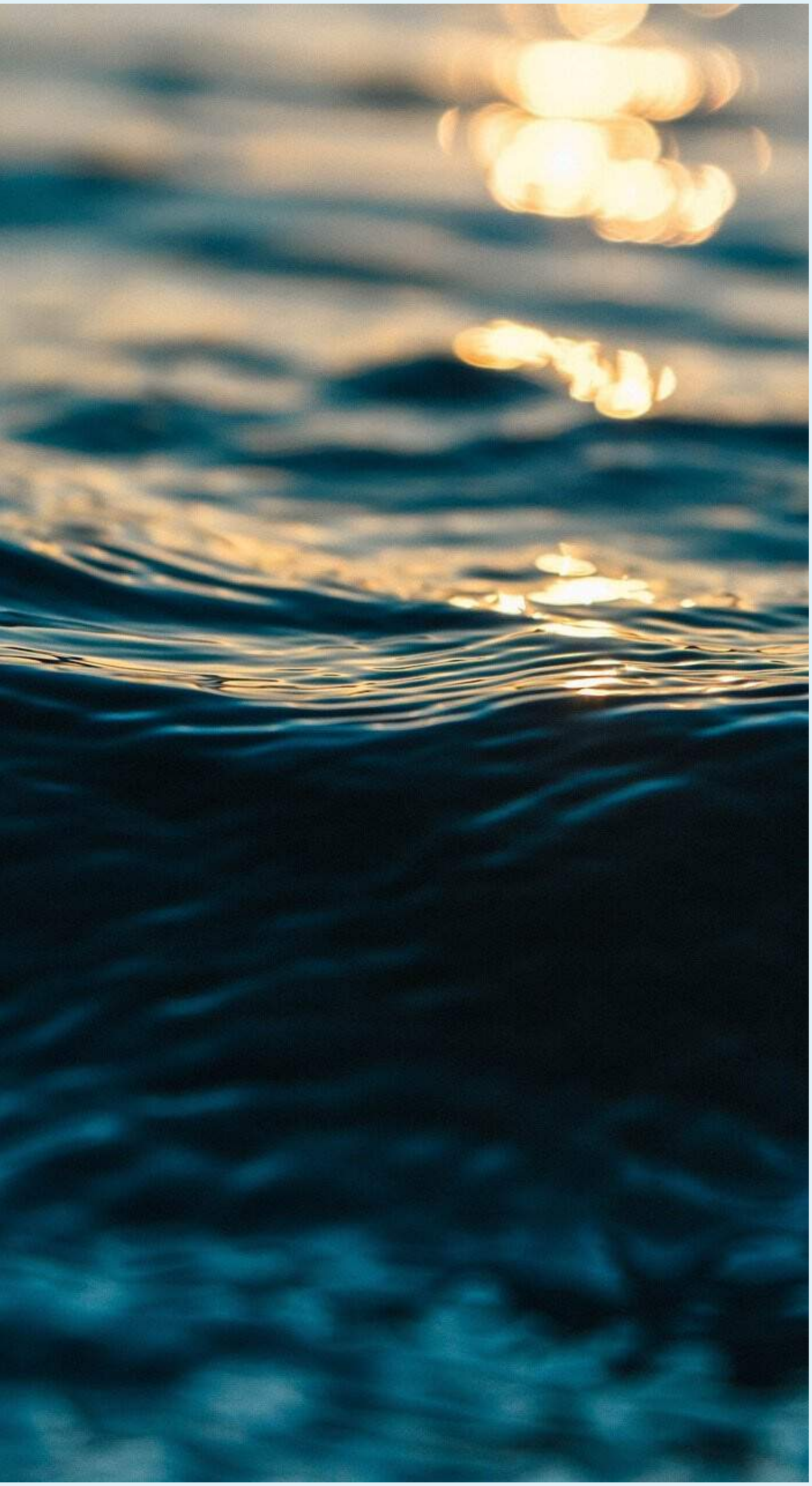

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Executive Summary

The Columbia University SIPA Benito Juarez Rainwater Harvesting (RWH) Capstone team recommends the expansion of rainwater harvesting systems to the 25 buildings as determined by the CBA and GIS data developed by the team below.

Background

Water scarcity is a critical infrastructure problem in Mexico City, which suffers from one of the highest demands for water of any city in the world—approximately 300 liters per person per day. But due to depleting aquifers, climate change, and surging urbanization, the gap between what residents require and what the city is able to provide widens.

Our team was tasked with exploring the feasibility of expanding rainwater harvesting (RWH) systems to residential and commercial areas in Benito Juarez.

RWH, the process of collecting rainwater from impervious surfaces (like rooftops) and storing into cisterns for later use, is a technique that has been employed for millennia across the globe. After carefully reviewing academic literature, analyzing applicable case studies, and interviewing over 20 subject matter experts in academia, government, non-profits, and social enterprises, we conclude that widespread implementation of RWH systems by the Municipality of Benito Juarez can alleviate water stress across the Cutzamala-Lerma grid, especially for Mexico City's most vulnerable communities.

To assess the unique issues, behaviors, and opinions surrounding water use and RWH of the Municipality's residents, we conducted a survey of over 400 households. Despite water scarcity not being a critical issue in Benito Juarez, our questionnaire revealed residents' concerns with intermittent water access and high utility prices. Residents responded enthusiastically towards RWH installations in their communities. This presents an opportunity for the Municipality of Benito Juarez to position itself as a leader in environmental sustainability.

Next we conducted a comprehensive cost-benefit analysis (CBA) to systematically appraise the tangible and intangible benefits of RWH against the various economic factors. The CBA consisted of two parts: a break-even analysis to compare costs to benefits and an assessment of possible returns on investment in both conservative and optimistic scenarios. Based on the assumption of water price, water consumption, and installation costs given to us by the municipality, we found that installation of RWH systems is recommended in the long term for the buildings in our sample.

Overall, the potential installation of RWH systems was found to cover 15.83% of a building's water consumption. Average Net Present Value was found to be 121,434 pesos, with an average payback period of approximately 6 years. For larger buildings, a larger tank size was found to provide higher returns in the cases of using a collective RWH system for a group of rooftops. Alternatively, using a smaller tank size but installing an individual RWH system for each rooftop provided higher returns in most scenarios. However, buildings with extremely large or small rooftops in our sample provided negative returns, and so tank sizes must be tailored to these rooftops. Finally, the imposition of a subsidy of 5,000 pesos to incentivize building owners to implement RWH systems was found to provide a higher net benefit to RWH over time.

The CBA results shaped the recommendations made in our roadmap to scalability, including the building criteria and material selection, possible timeline, institutional governance, regulatory criteria, risk mitigation efforts, and public education.

Roadmap to Scalability

First, we recommend establishing an expert working group. This working group will consist of water engineers, urban planners and policymakers from Benito Juarez's government. Second, this group will then create feasible project plans to analyze the distinct requirements for each of the recommended 25 edifices in the residential and commercial areas. Third, these project plans will serve as a foundation with which the government will communicate with neighborhoods to build consensus and collect residents' opinions on the project. Community buy-in and collaboration is key in making RWH successful and expanding it at scale. Once the community and the government have agreed on the plan, then it can be finalized.

Implementation Recommendations

Within 1 to 3 months, allocate funds with which to begin these RWH projects. Funds should be allocated properly to cover expenses for contracting with RWH engineering companies as well as possible support services that the companies may need.

After 2 to 3 weeks, begin the vendor selection process. Align goals for the municipality with the goals for the engineering company. Develop a clear understanding of water quality standards, system components, maintenance requirements, and general operations.

After agreements have been finalized between the company and the Municipality, create a social media and pamphlet marketing campaign that contains information on the environmental, ecological, and social benefits of RWH. Within 6 months to a year, employ engineers from the contracted company to monitor, evaluate and improve the RWH system, as well as offer support services to residents.

Background on Mexico's Water Issues

Mexico City suffers from one of the highest demands for water of any city in the world. At 300 liters per person per day, the city has a large gap between its supply and demand. While water access for the city has always been a challenge, the trifecta of an increasing population, climate change induced drought, and aging infrastructure makes it difficult for the city to effectively supply water at all times of the day. 2017 and 2018 saw a number of shut down periods where the Cutzamala system was forced to shut down the water supply for 1) lack of water 2) decreasing water pressure in existing pipe systems and 3) government induced rationing.

Water shortage problems have plagued the city for over ten years. Mexico's per capita water volume has decreased in recent years, calculated by taking[1] into account the population growth and natural water distribution. The daily average water supply is 315 liters/inhabitant/day in Mexico City, which is higher than the national average, 135-195 liters/inhabitant/day.

In wealthy areas, one person is able to use up to 600 liters, while for poor areas, use is only around 20 liters. At least a fifth of the population does not have reliable tap water service. Additionally, many citizens have an intermittent water supply. About 70% of the city has fewer than 12 hours of running water every day. In some areas, 18% of citizens need to wait several days for just an hour of water supply.

This water crisis is occurring for several reasons. On the demand side, the increasing resident population is the major contributor. In recent years, Mexico has transferred from a rural centralized to an urban centralized[3] country. As one of the world's largest cities, Mexico City is home to around 21 million people and the number could rise to 27 million if surrounding areas are included. About 20% of Mexico's population lives in the capital.

Experts estimate the the city's population will probably grow to 30 million people by the year 2030, which will exponentially inflating water demand. Additionally, SEDEMA estimates a 13% to 17% contraction in the natural availability of water by 2050.

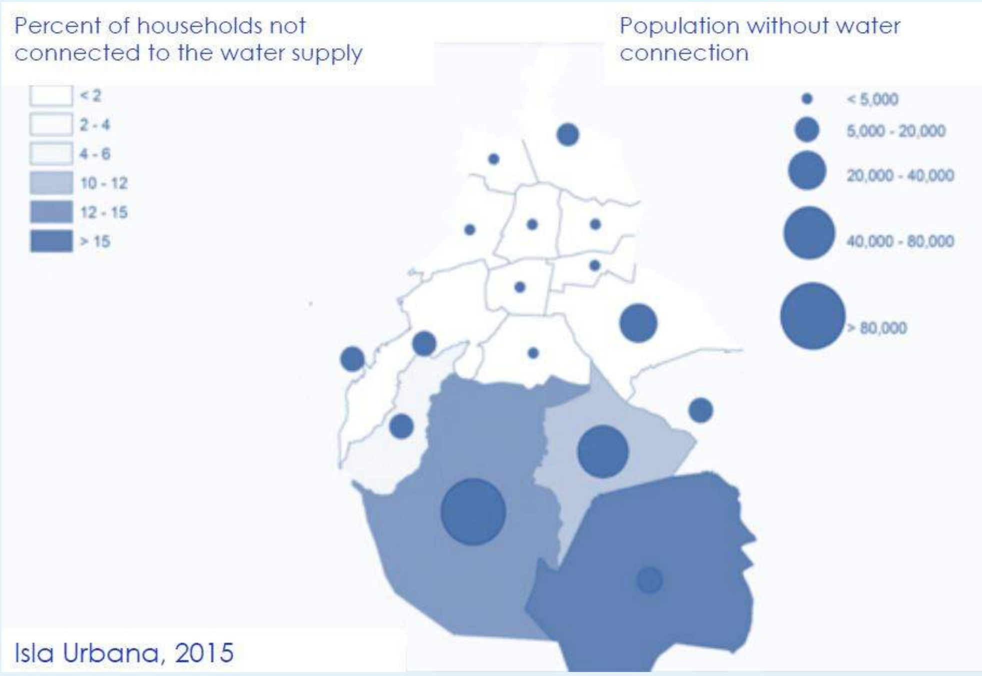
On the supply side, Mexico City is a water paradox: it suffers from flood risk as well as a water shortage risk. 40% of Mexico City's water depends on freshwater reservoirs and the rest comes from the valley's vast underground aquifer. Imported water is energy-intense and expensive to use and the underground water resources are overexploited. The recharge rate of the aquifer is about 31.6 m3/s, much lower than the abstraction rate of 59.5 m3/s, resulting in a deficiency of about 28 m3/s.

Overexploitation has led to land subsidence, which in turn damages the water network, leads to leakage, and increases the pressure of water supply, not to mention that the infrastructure of Mexico City's water networks is inefficient and ageing. It is estimated that about 40% of water is leaked in the grid during the supply process before arriving to households. On top of the aforementioned challenges, water resources in Mexico City are quite vulnerable to global warming.

Mexico is expected to have a 2-4 degree increase in temperature and a 5-20% decrease in precipitation annually, due to global warming. This induces the corresponding effect of less but more concentrated rainfall, increasing water stress and flood risk, especially considering the city is located in an endorheic basin.

The wetter season in Mexico City could last 4.4 months, with the highest chance of a wet day peaks at 79%. Climate change could reduce surface water availability due to the evaporation effect, as well as groundwater sources in the long run. With this current situation, it may be time to adopt an alternative water supply method, like RWH.

Benito Juarez is a wealthy residential area, mainly populated by the middle and upper classes. Although 20% of the population lives below the middle-class threshold, the wealth gap is still significantly lower than other areas in Mexico City. 58.9% of the total population is economically active, with a low unemployment rate under 1%.



Source: Kristen French, "To ease Mexico City's Water Woes, Look up, Study Suggests."

Why Choose Rainwater Harvesting?

Rainwater Harvesting (RWH) has proved to be a promising and effective application to address multiple water issues. This system is a type of harvest in which the rainwater is collected and stored for further use, rather than letting it run off. RWH may be a good option for Mexico City and Benito Juarez (BJ), as there is enough rainfall but not enough groundwater supply. RWH not only provides reliable, clean water resources, replacing expensive, inefficient and energy intensive water resources, but also exploits the advantage of heavy rainfall in Mexico City, avoiding the flood risk and making up the deficiency of water infrastructure.

RWH could mitigate water shortage, especially for low income citizens. Currently, Benito Juarez has implemented a pilot program limited to the municipality. However, RWH has great potential to source water for the poor, who have been suffering from water shortages for many years.

Some poorer districts in the southern part of Mexico City, such as Ajusco in the borough of Tlalpan, are not connected to the water grid.

RWH could offer an independent water supply for residents during the rainy season and even in drought season with advanced storage technology. Columbia University Earth Institute research demonstrates that a typical RWH system could satisfy 60% of inhabitants' daily water needs. After the initial setting up, further maintenance cost is quite low.

In addition, RHW is environmentally friendly and could significantly reduce energy consumption for the water supply system. The city's water system is energy and carbon-intensive, mainly due to the attributes of its overexploited aquifer. Often, the energy and climate consequences of water are not recognized. For example, the acts of pumping, treating and delivering water to consumers use energy. In the U.S. water uses 3% of electricity generated. According to the EPA, reducing water demand by 10% would save 300 billion kilowatt hours of energy, which in turn would save carbon emissions. Using alternative water technologies, such as RWH, can help decrease demand, and the impact on reducing CO2 emissions is critical.

However, the EPA states that carbon reductions tied to RWH are not enough to significantly impact climate change. A comparison of energy consumption and the Global Warming Potentials of European and Mexican water systems shows that Mexico City consumes 2.6 kWh for every 1 m3 of water, while the number is only 1.7 for Aveiro (Portugal) and 1.9 for Tarragona (Spain). Research ascribes the major difference to water abstraction, which consumes a massive amount of energy, due to the water leakage mentioned above. As massive amounts of water run off the system, the municipal water grid is not able to achieve the pressure point to force buildings to pump the water. Therefore, in order to extract water, more energy is used up.

A study indicates that a building with a RWH system could lower global warming potential by 10% to 18 %, and lower cumulative energy demand by 18% to 29% compared to a non-RWH building.

Applying RWH widely could mitigate flood risk by decreasing rainfall peak discharges, runoff volumes, and velocity. In Nanjing, China, a study shows that the RWH system has a great performance in reducing flood volume of 13.9% maximum daily rainfall, 30.2% annual average maximum daily rainfall and 57.7% critical rainfall.

Another study shows that if the RWH tanks are installed, flooded areas can be reduced up to 100% when small rainfall events happen.

Additionally, in research carried out in Mexico City Paulina Larrauri of the Earth Institute explains that to fully understand the benefits of RWH, certain benefits must be analyzed from the perspective of different stakeholders, including developers, policy makers, entrepreneurs, property owners, water facility managers and equipment manufacturers. Below is a list of possible benefits for various stakeholders.

- *Property owners*: water access, improved health, cost savings in water bill, reduction in water supply interruptions
- *Entrepreneurs*: business opportunity through the sale and maintenance of RWH systems
- *Policy makers and water managers*: societal benefits, including long-term water availability, reduced flooring, improved water quality, climate change mitigation

Lastly, Yu states that decentralized technologies, including RWH, can "foster flexibility and innovation by making use of local resources, creating partnerships and by enhancing participation, communication and feedback."

Introduction to RWH In Mexico City

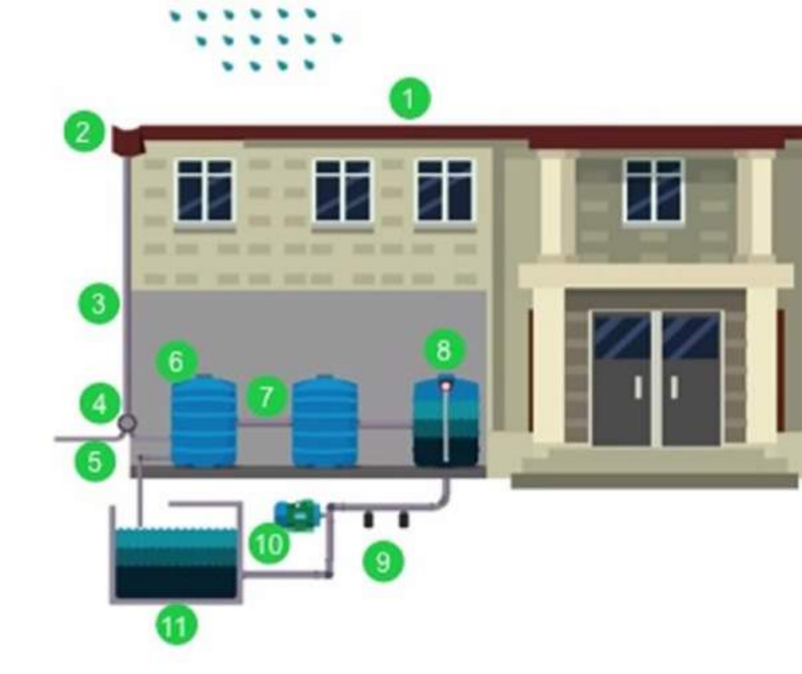
System Design

RWH systems can have several types of designs, customized for where it is located. For example, systems can be placed in individual residences, apartment buildings, commercial buildings, and community set-ups. Factors to consider when designing systems for different types of locations include rainfall patterns, construction types, water demand patterns and building use, existing infrastructure, and water cost.

In Mexico City, the materials used for a RWH system remain similar to materials used in other projects. Likewise, the design of the system is the same. First, the rain that falls onto the roof must be collected. This requires the installation of a gutter, typically plastic or metal, on one or multiple edges of the roof (number 2 in the image). From here, the water passes down a PVC pipe (number 3) to an exchange valve which removes the dirty water from the first rains in a process known as first flush (number 4).

At this point, the water is carried into a series of PVC plastic storage tanks (numbers 6, 7, and 8) where a series of pipes transfer the water down into a filtration system (number 9) and finally into the collective cistern (number 11).

The addition of a pump (number 10) helps the system run more efficiently by increasing the speed of water flow. The most common materials for these types of systems include PVC piping and fittings, plastic storage tanks for water storage, and the plastic gutter installations.



Source: SCALL Tech H4O

Current Initiatives

In Mexico City, RWH is becoming more popular as a supplemental water source. Generally, most work is focused on marginalized communities with intermittent access or no access to potable water. According to Larrauri, various entrepreneurs have installed over 12,000 systems since 2009 in marginalized communities. Nongovernmental organizations (NGOs) Cantaro Azul, Isla Urbana, Neta Cero, and Fundacion Rıo Arronte have “developed a web application to calculate the potential water savings and system costs for individual RWH systems anywhere in Mexico for rural and urban areas in the domestic and education sectors.” Overall, RWH can be found in office buildings, schools, housing and some public buildings.

At a government level, some regulations have changed in order to promote RWH. For example, a Water Law was passed in 2003, requiring all new construction to[27] have RWH systems. In 2011, a law of mitigation and adaptation to climate change and sustainable development in Mexico City put in place the same requirements.

The National Water Commission (CONAGUA), which operates at the national level, has developed the National Program for RWH and Eco-techniques in Rural Areas. In 2019, the Mexico City government committed to installing 10,000 RWH systems in low-income housing buildings in the boroughs of Iztapalapa and Xochimilco.

By 2025, Mexico City aims to install 100,000 RWH systems in homes, including many that depend on water deliveries from tankers. In total, the government will invest $10.5 million to this program, focusing on Iztapalapa and Xochimilco. 80% of this amount will go to materials, 15% in installation and beneficiary training, and 5% on promotion and monitoring activities. There have been several other successful initiatives, including:

1. *Torre Reforma*: This skyscraper, measuring 246 meters and 55 stories, was partly built to help encourage more green building in Mexico City. In 2016, Torre reforma received the LEED platinum core and shell certification with 45 credits. In terms of water, 100 percent of rain and wastewater are reused after going through a water treatment plant, for bathrooms and air conditioning purposes. Storm drains located in the lower basement harvest rainwater and reuses it throughout the building. Additionally, treated wastewater serves street level and low rise irrigation needs.
2. *Torre BBVA*: This LEED-gold certified skyscraper, measuring 235 meters and 50 stories, minimizes its energy footprint through passive heating and cooling, RWH and energy efficient lighting.
3. *Plaza Carso II*: This mixed-use development complex claims to be the largest in Latin America. The complex uses RWH and water reuse to promote sustainability for all of its clients. With a net construction area over 211,000 square meters, this project has a large potential for rainwater capture.

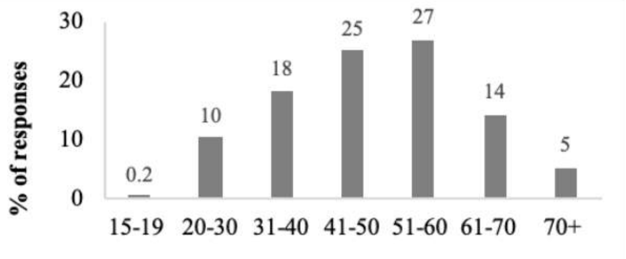
Buildings & System Selection

Water Use and Trends

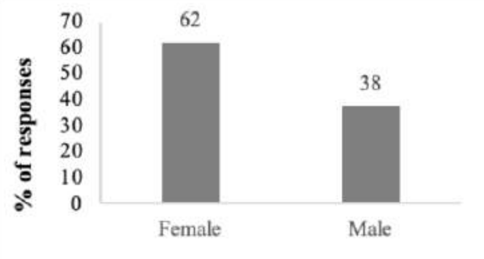
To assess the unique behaviors, needs, and opinions surrounding water use and RWH, our cohort surveyed Benito Juarez residents using social media. The survey was done over the course of one week and was sent to key actors to get residents' perspectives from different areas of the Municipality. The goal was to collect data on stakeholders' perceptions about the use of RWH systems in their homes; it was also designed to measure perceptions about the utility of these systems to face future water shortages. The survey provides justification on whether scaling up RWH can address water shortages in Mexico City, and if so, if it is possible to do so. Certain areas in the municipality have problems with water pipes—such as leaks in the infrastructure—which have left the population without water for days. By implementing IoT to measure harvested rainwater volumes in real time, the city is not only transforming itself into a smart city and improving decision-making in regard to water management, but it will also be providing better solutions to be more efficient with the use of one of the most valuable and vital natural resources: water. It will further work towards becoming a genuinely self-sustained municipality.

All responses were synthetized to show collective results. The open-ended questions were codified, for example, the question around the main concerns about the water or water service you receive in homes. Also, the question about how much would the people be willing to pay for a RWH system that would guarantee you a more stable water source, and the uses of water from rainwater systems because people stated that they probably use that water in more than once activities in their homes. Finally, all prices/cost that the people statement is in Mexican pesos (MNX).

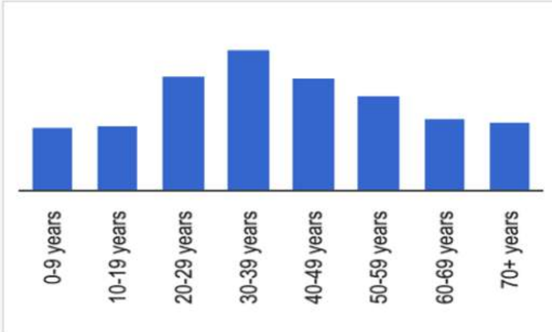
The questionnaire, published on the Municipality webpage and disseminated by community leaders, contained 34 questions divided between two research goals: determining water usage challenges in Benito Juarez (Survey 1) and assessing how residents feel about RWH (Survey 2). We received 417 responses.



Graph 1: Ages range (Source: Survey 1)

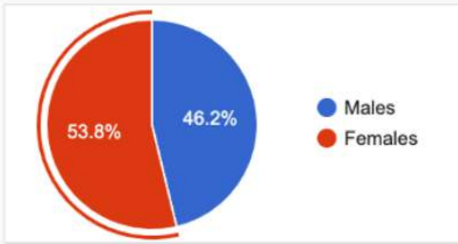


Graph 2: Gender (Source: Survey 1)



Age Distribution (E 2015)	
0-9 years	36,475
10-19 years	37,211
20-29 years	64,772
30-39 years	79,899
40-49 years	64,145
50-59 years	54,390
60-69 years	41,031
70+ years	39,315

Graph 3: Ages Distribution in Benito Juarez (Source: citypopulation.de)

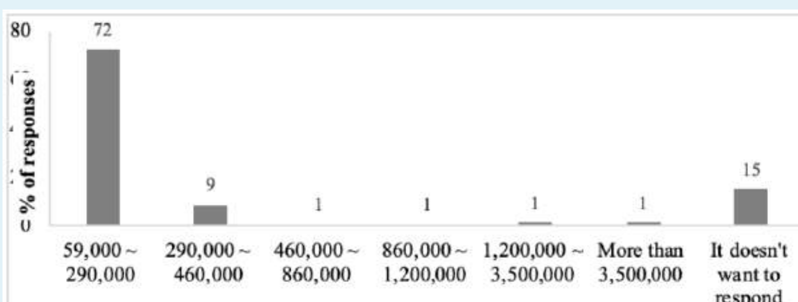


Gender (E 2015)	
Males	193,007
Females	224,409

Graph 4: Gender Distribution in Benito Juarez (Source: citypopulation.de)

The age of the respondents ranged from 15 to over 70, among which 27% are 51 to 60 years old, and 25% are 41 to 50 years old. The survey sample graph and Benito Juarez population graph has a similar shape. But the sample has more 41 to 60 year-olds than the 20 to 39 year-olds, indicating that the samples we choose are slightly older than the overall population.

62% of our respondents are female and 38% are male. Compared with the demographic in 2015, which also shows that the percentage of female citizens (53.8%) is higher than that of male citizens (46.3%) , we have a large amount of female respondents, indicating that our survey result is more inclined to female opinions.



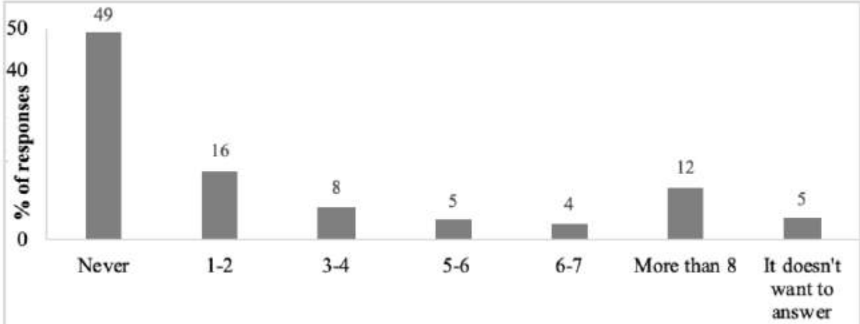
Graph 5: Income (Source: Survey 1)

Benito Juárez is one of the wealthiest municipalities in Mexico City. Accordingly, 15% of participants stated that they have an income between $59,000 MNX to $290,000 per year. 9% reported an income between $29,0000 and $46,0000 MNX per year, and 15% did not want to answer the question.

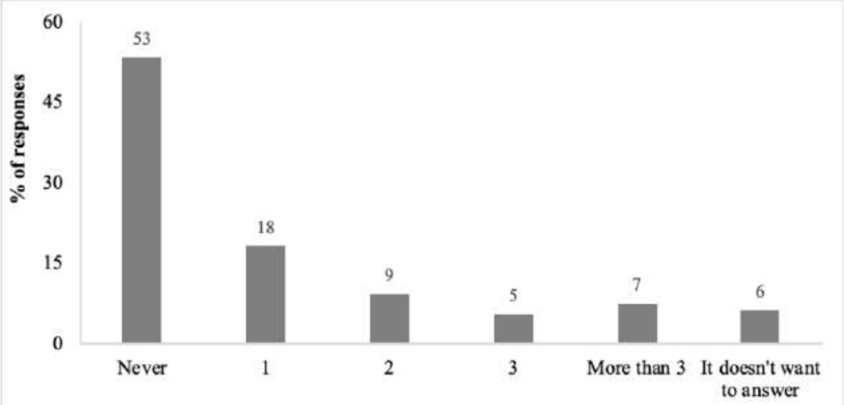
The key findings from the survey can be divided into 3 sections:

Water Scarcity

Water scarcity refers to the lack of sufficient available water resources to meet the demands of water usage within a region. It's the fundamental problem the RWH plan addresses. The survey data tries to determine whether there is a problem of water scarcity in Benito Juarez that awaits to be solved, and therefore justify the necessity of introducing an alternative water source like rainwater in Benito Juarez.



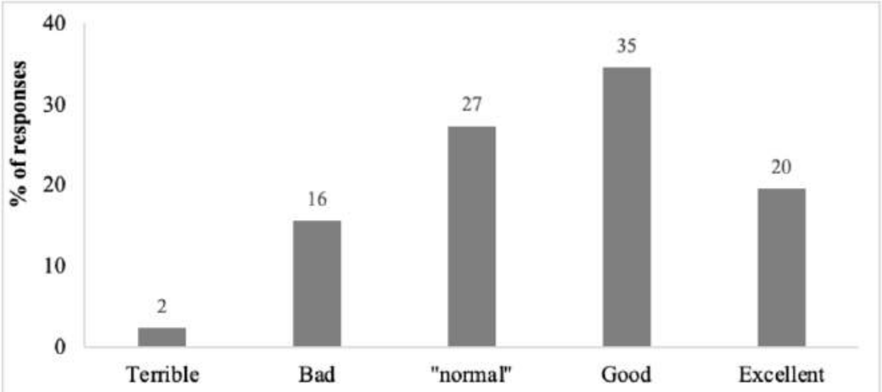
Graph 6: Hours without water per day (Source: Survey 1)



Graph 7: Days without water per week (Source: Survey 1)

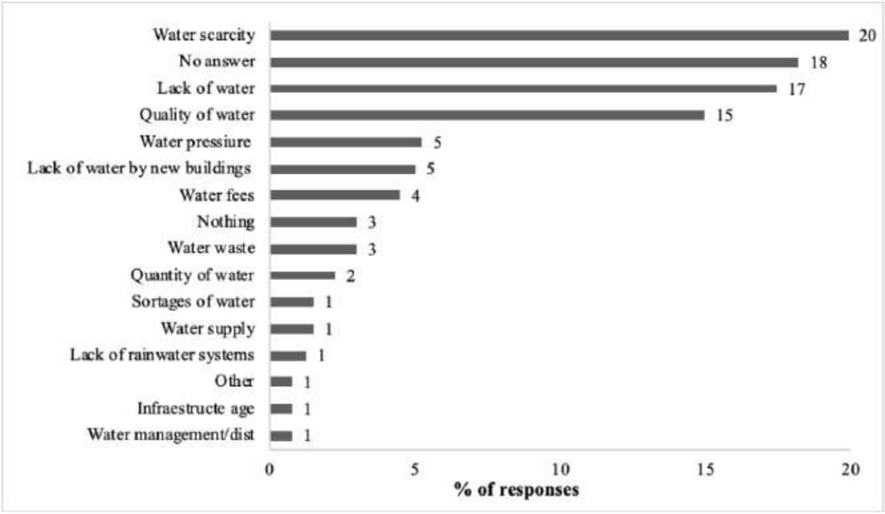
Graph 6 shows the percentages of hours without water per day. 49% of our respondents have continuous water supply in a day, while 16% have 1-2 hours per day without water and 12% have no water for more than 8 hours. 53% have running water for the whole week, while 18% have 1 day without water.

In terms of days without water per week, more than 50% of participants (53%) reported never having had such problems with water. 18% of the participants reported that they do not receive water one day a week, 9% reported living without water two days per week, 5% reported three days without water per week, and only 3% of participants reported problems with water for more than three days a week.



Graph 8: Perception of access to water (Survey 1)

55% of respondents are satisfied with their access to water (35% "good" and 20% "excellent"), 27% of responses say that the access to water is "normal" (no problem with water access). Only 16% of responses said that the access to water is bad and 2% "terrible".

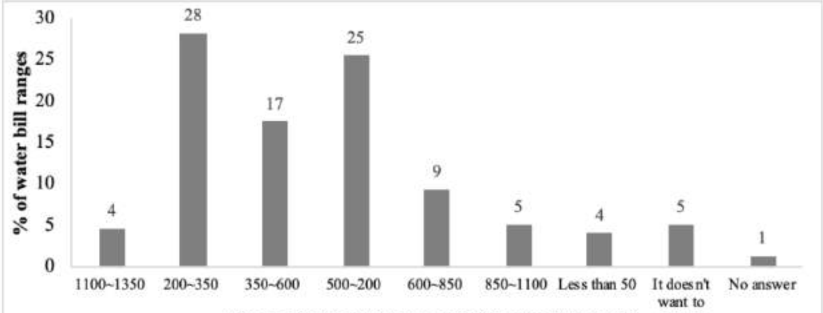


Graph 9: Concerns about water (Source: Survey 2)

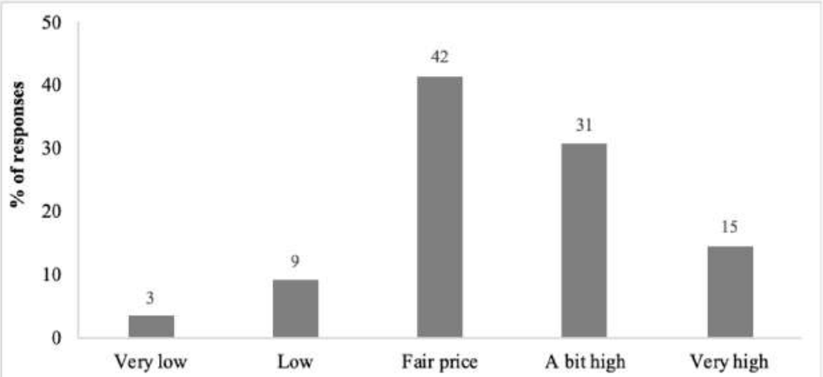
However, the biggest concern of our respondents about water is related to water scarcity (20%). In general, the perception of access to water is good. The residents in Benito Juarez don't consider themselves having much problem with the water. Apparently, Benito Juarez is not experiencing an urgent water shortage. However, about half of the respondents experience 1 to 2 hours of water outage a day and people are concerned about the water scarcity problem. Wealthy and developed as Benito Juarez is, the ideal condition should be continuous water supply 24 hours a day, 7 days a week. With the rich water resources that come with abundant rainfall, the non-stop running water is very likely to happen within Benito Juarez.

Water Cost

The water cost here refers to the amount paid by Benito Juarez residents for their monthly running water. We want to know what people think of their water bill, and how much money they spend on other water sources. If it imposes an extra financial burden on average residents, are people expecting a RWH system to lift the burden?



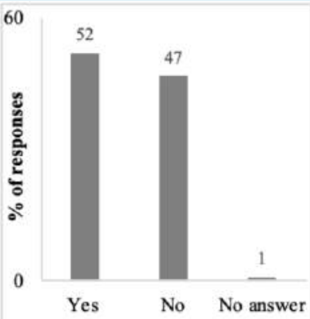
Graph 10: Monthly water bill (Source: Survey 1)



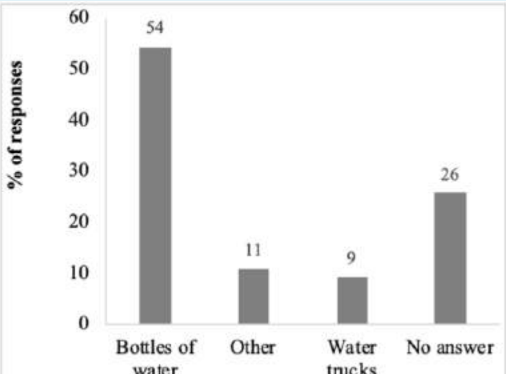
Graph 11: Perception of water cost (Source:Survey 1)

Graph 10 shows the percentages of water price ranges that respondents reported. In the first place, respondents mentioned paying between $200 and $350 MNX for water (28%). Then, 25% of responses mentioned paying between $500 and $200 MNX—in other words, the average amount that people said they pay for water is between $200 and $500 MNX. Additionally, 17% of responses reported paying between $350 and $600 MNX. Finally, less than 10% of the responses stated that they pay more than $600 MNX.

Graph 11 shows that people are not unhappy with the water price. 42% of participants reported that they pay a fair price; 31% of participants reported that the fee they pay is a bit high; 15% of participants reported that they pay a very high fee for water; 9% of participants reported paying a low fee; and only 3% reported that they pay a very low fee. In short, the water bill in Benito Juarez is fairly affordable for average citizens.

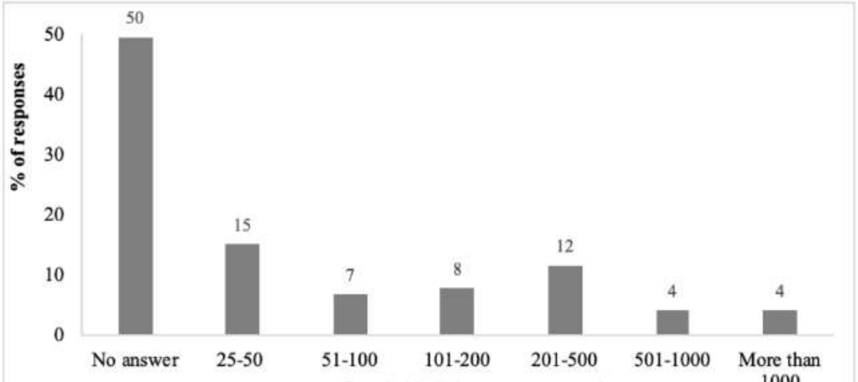


Graph 12: Use of other water sources (Source:Survey 1)



Graph 13: Other water sources (Source: Survey 1)

Another part of water expense is the amount paid for other water sources. According to Graph 12 and 13, 52% of respondents use other water sources, and the most used source is bottles of water (54%), while water trucks only take 9%.



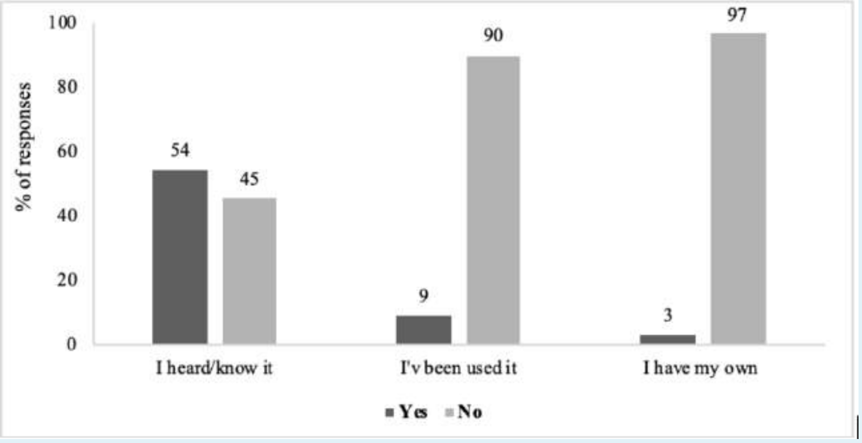
Graph 14: Other water source's cost

Comparing the water bill, the other water source’s cost is not significant. As Graph 13 shows, half of the respondents did not answer the question, though 15% of participants reported paying between $25 and $50 MNX, and 12% reported paying between $200 and $500 MNX. This difference between prices of other water sources is because these water sources can be bottles of water or private water trucks. Also, it depends on the frequency that people buy such water.

In sum, the respondents have no problem paying the water bill, and the other water sources like bottled water and water trucks impose limited financial burden.

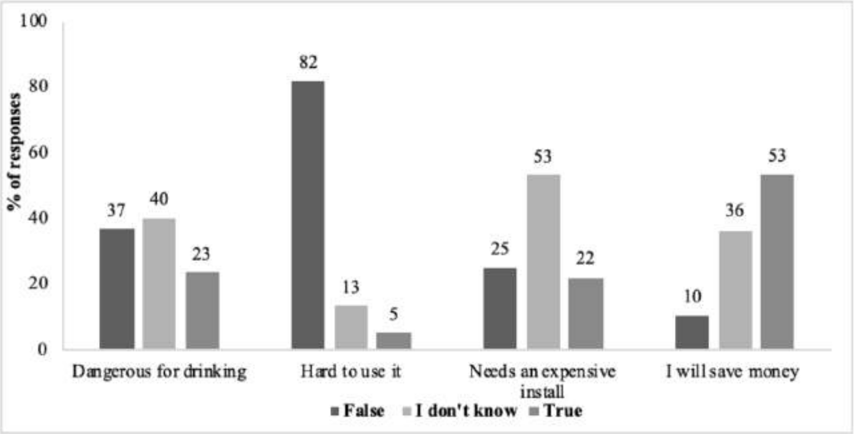
Public Perception on Rainwater Harvesting

In the third part, we tried to figure out how much the respondents know about RWH and what their concerns are. In this way, we want to make sure that the system designed can better meet the expectation of the public and fill the knowledge gap to facilitate the implementation of the RWH system.



Graph 15: Responses on rainwater harvesting system knowledge (Source: Survey 2)

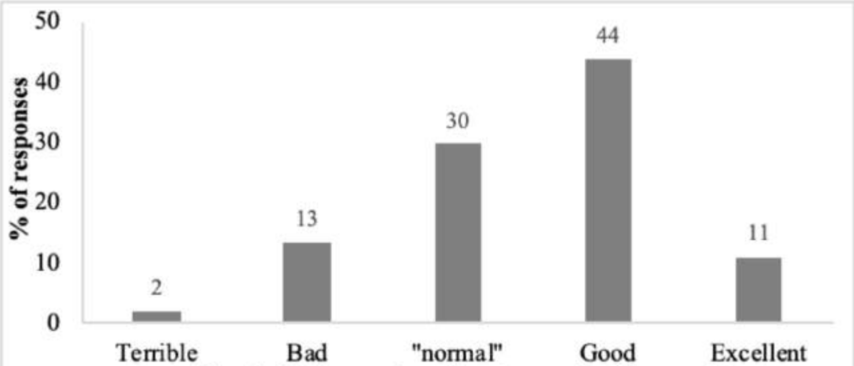
In terms of perceptions about the use of rainwater systems, it was a priority to see if people were aware of this type of system. In the survey there were three key questions regarding whether people had heard of or knew about the systems, if they had used one, and if they had their own system in their homes. Graph 15 shows these responses. The 54% of responses reported knowing about such systems, while 90% of responses reported never having used one, and more than 90% stated that they do not have their own.



Graph 16: Responses on rainwater harvesting system expectation (Source: Survey 2)

In terms of participants' perceptions about the use of RWH systems in their daily lives, 40% of respondents said that they do not know if the water from these systems is dangerous to use, while 37% thought that it is not dangerous. 82% said that it is not true that these systems are hard to use, and more than 50% said that they do not know if the installations are expensive or not. Finally, 53% of people said that it is true that they would save money using these systems in their homes. 35% consider their access to water as "good", followed by 27% of "normal" and 20% of "excellent". Meanwhile, 44% think their water quality is "good", 30% think it is "normal" and 13% "bad". About the water usage fee, 42% think it is fair, while 31% think it's a bit high and 15% think it is very high.

In short, respondents are positive about rainwater. They expect the RWH system to be easy to use and will save money for them. However, they're uncertain about whether the rainwater is dangerous for drinking and are concerned about the installation fee.

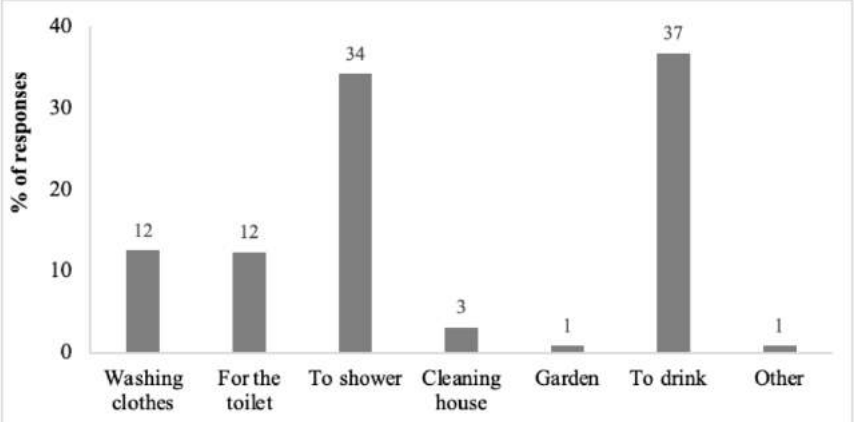


Graph 17: Perception of water quality (Survey 1)

On the other hand, the public is feeling good with the current water quality now, with 44% of respondents participants is that they have good quality water (44%); 30% of responses agree that they have "normal" water quality; 13% of responses said that they have bad water quality; 11% reported having excellent water quality; and only 2% of participants stated they have terrible water quality.

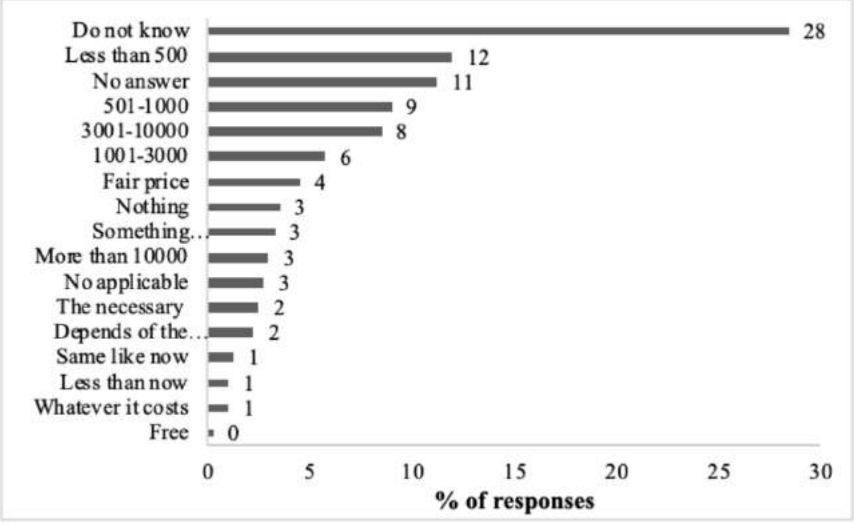
Comparing the satisfaction of current water quality and the concern about rainwater, the municipality should promote public campaigns and education on rainwater quality and set some processing in RWH systems to clean the water.

Meanwhile, in order to meet the expectations, the municipalities can make policies that subsidize the installation and usage of rainwater, deducting the cost and attracting more users.



Graph 18: Uses of harvested rainwater in homes (Source: Survey 2)

Under the premise that rainwater collected has good quality, 37% of the participants said that they would drink the water. 34% said that they would use it to shower with and 12% of responses said washing clothes.



Graph 19: Willingness to pay for rainwater harvesting systems (Survey 2)

The respondents expect the water bill of a RWH system, which would guarantee a more stable water source, to be low. 28% of the respondents are uncertain about the payment, while 12% of participants said that they would like to pay less than $500 MNX for such a service, 11% of participants did not provide an answer, and 9% reported paying $500 to $1000 MNX. The rest of the responses were less than 10% of the total.

The residents in Benito Juarez are reacting positively about the RWH system, expecting a more sufficient water supply and a low monthly cost. If the municipality deals with their expectation on cost and quality in a good way, it’s highly likely that the RWH system will be warmly welcomed by the people.

In conclusion, Benito Juarez is not experiencing an urgent water shortage, but some residents are experiencing water outages from time to time. People are concerned about the water scarcity problem, and the introduction of a RWH system can be a reliable supplement of the current water supply system.

Although most respondents have no problem paying the water bill, they still hope the RWH can cut their cost. The overall perception of the RWH system is good. When building the system, the municipality's effort on cutting installation and usage cost will be very much appreciated by the residents.

Building Selection

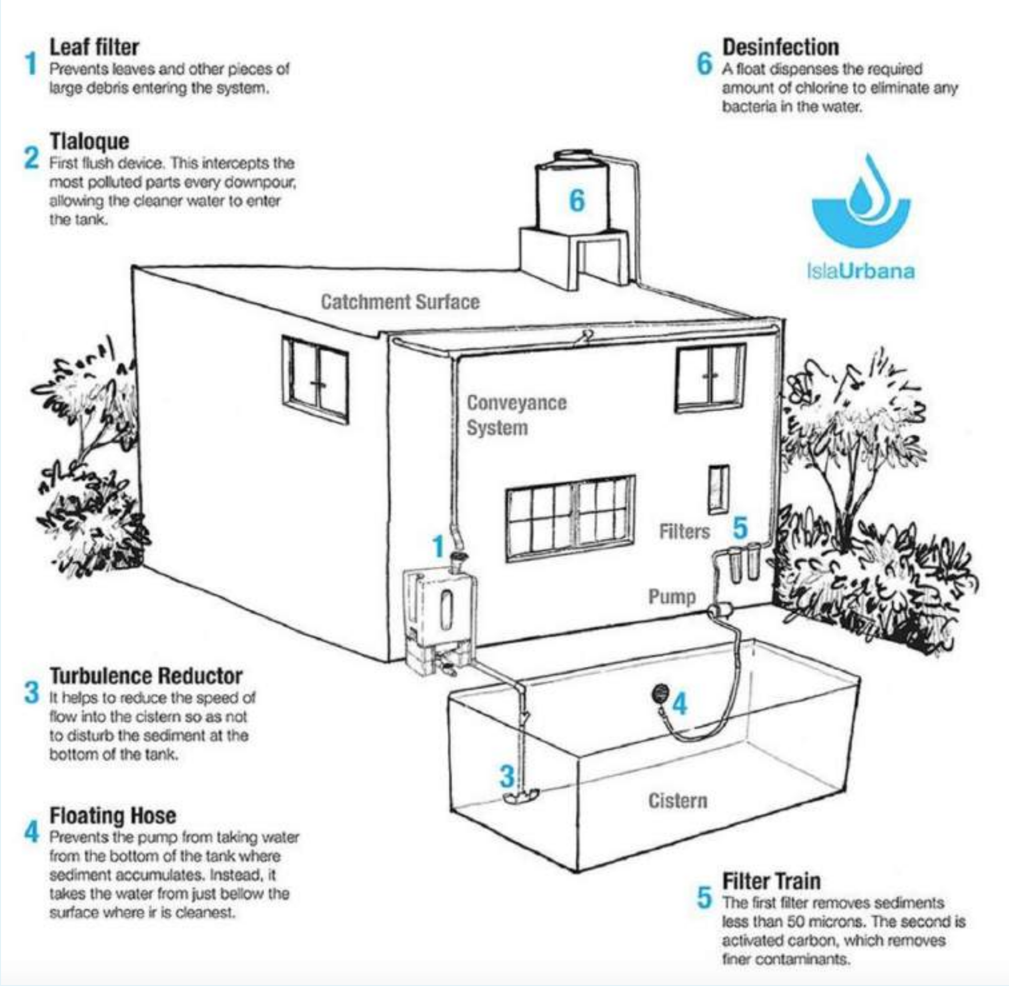
The selection of buildings within the Municipality of Benito Juarez for adoption and installation of a RWH system is dependent upon two primary considerations of data: physical building type and site considerations. Understanding the metrics which are used to calculate each of these is critical to making the best building selection possible. If, for example, a building with a considerable rainfall capture potential has very few occupants, the low demand for water will mean a lower Net Present Value (NPV) for consideration. Essentially, while rain capture is large, a system installed on this building will take longer to pay off than, say, a small apartment complex with a higher demand. In each of the sections below, these considerations are quantified and explained in greater detail.

Demand for water and rooftop area are the two essential variables to consider when evaluating buildings for RWH systems. The first, water demand, is dependent upon the number of occupants in the building and the function of the building. Indeed, a commercial building will use a different level of water than a residential home or apartment. Incorporating these different levels of water demand into building selection is critical. Rooftop area, on the other hand, is a static variable, meaning it does not vary by building type so much as the overall size and dimensioning of the building itself. In the quantifiable analysis that was performed as part of this project, each of these variables was kept as constant. The first, rooftop area, was the single independent variable in the NPV value calculations. As such, the water demand for each building was assumed to be a function of the rooftop area of that same building. Consequently, as the rooftop area of each building changed, this changed a number of secondary variables including water demand which ultimately varied the NPV of the system’s installation.

While quantifiable data is a significant aspect of the calculations performed in this project, they were not the only considerations made when evaluating building selection. In fact, it was the consideration of each site which ultimately led to the final recommendations. Site considerations are the qualitative analyses that help provide a moral or ethical variable to a cost analysis. In this project, the qualitative elements of the project were obtained from the survey mentioned above. Provided that hundreds of responses were gathered, the source was considered to be reliable for analysis.

The survey's greatest takeaways from the perspective of site selection are that people are interested in RWH and, on average, are inclined to want to pay more for the systems so long as they provide clean and constant water supply. Given this, residential units were given slight priority to commercial or industrial units. The justification for this decision comes from a policy level. If citizens become more acquainted with rainwater systems from one another, there will be a stronger political push to install them at commercial and/or industrial levels. In any case, the recommendations support the above narrative and provide a municipality-wide selection of buildings.

The choice of material for each component of an RWH system will affect the structure's overall size, placement, and cost.



Source: Isla Urbana

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The choice of material for each component of an RWH system will affect the structure's overall size, placement, and cost. As is shown in the image above, a sample RWH system proposed by Isla Urbana includes plenty of parts that guarantees the quality of water collected, including the leaf filter, the tlaloque, the turbulence reductor, the floating hose, the filter train, the filters and the disinfection. Such parts are small and require special concern. Calvin Firth proposes 5 must-have rainwater harvesting components: the collection area, conveyance system, first flush diverter, leaf screens and water storage tank. This material section focuses on the materials used for the major parts, including cistern (storage tank), conveyance system, including pipes, downspouts and gutters, and catchment surface. The 3 parts are of great importance, because the water collected is mostly flooding on or within them. Since the 3 parts share a similar function of storing and transmitting the rainwater, it's suggested that they used the same material. the materials used for the 3 parts need to meet the criteria of:

1. Light, so as not to put too much weight on the buildings to ensure residents' security;
2. Stable, and can endure extreme weathers and durable for at least 5 years;
3. Commercially viable, to avoid adding too much financial burden to the municipality and the residents.

Among all materials, we recommend fiberglass, polyethylene and galvanized steel. They all share the benefit of low cost, stable and light. But they all have disadvantages, which should be considered when evaluating the building condition. Fiber glass can only be used on smooth, solid and level surfaces. It can be used for underground water tanks and collection areas. Polyethylene must be installed above ground and is UV-degradable. It should be installed on farms and ranches, or buildings with a large space surrounding it. The contractors should take the possible harmful Polyethylene particles into consideration. Galvanized steel can rust or face corrosion. It should be used for collection area, pipes and above-ground tanks, not underground tanks where water and mud accelerates erosion.

The recommendations given in the chart below should be combined with the government budget, residents' preferences and the technology used by contractors. When working in Benito Juarez, it is important to consider local supply chains and available materials for RWH system construction.

Material	Features	Cost	Pros	Cons
Plastic				
Fiberglass	Can range from 50 to 15,000 gallons; vertical cylinder & low-horizontal cylinder configurations	$0.50-2.00/gallon	Commercially available; moveable; alterable; durable	Needs to be on smooth, solid and level surfaces; must be opaque to prevent algae growth
Polyethylene/Polupropylene	Must be installed above ground; common on farms and ranches; capacities from 50 - 10,000 gallons	$0.74-1.67/gallon (polyethylene) and $0.35-1.00/gallon (polypropylene)	Commercially available; inexpensive; lightweight/moveable; alterable; long lasting	UV-degradable; must be opaque
Metals				
Steel drums	Used in urban or suburban settings; capacities from 150-2,500 gallons	$0.50-1.50/gallon	Commercially available; moveable; alterable	Need to make sure there are no toxics; Can rust or face corrosion
Galvanized steel tanks	Used in urban or suburban settings; capacities from 150-2,500 gallons		Commercially available; lightweight/moveable; alterable	Can rust or face corrosion
Concrete & Masonry				
Ferrocement	Low-cost steel & mortar composite material		Durable; immoveable; cost-effective	Can crack and fail; small cracks & leaks; need for structural engineer
Stone, concrete	Poured in place or prefabricated; can be constructed above ground or below ground; integrated into new constuction; more desirable tasted (calcium in concrete dissolved by rainwater)	$0.30-1.25/gallon	Durable; immoveable	Much upkeep/maintenance; prone to cracking & leaking; need for structural engineer
Wood				
Redwood, fir, cypress, pine, cedar	Common in urban and suburban settings due to aesthetic appeal; capacities from 700-37,000 gallons; need skilled technicians	$2.00/gallon	Aesthetic; durable; moveable	Expensive

Source: Krishna, Dr. Hari J. "The Texas Manual on Rainwater Harvesting." Austin, Texas: Texas Water Development Board, 2005.

The recommendations given in the chart below should be combined with the government budget, residents' preferences and the technology used by contractors. When working in Benito Juarez, it is important to consider local supply chains and available materials for RWH system construction.

Draft Agreements for Buildings

Developing legally sound documents and agreements between building owners, the Municipality, and the contractors is critical for the legal safety and sustainability of the RWH initiative and the project members as a whole. Given the countless elements of a scaled RWH implementation, providing a clear legal structure with which contractors and building owners alike can collaborate will ensure optimal participation and in Benito Juarez. Additionally, a clear structure provides a clear structure for dispute resolution and outlining responsibilities. As a whole, the process can be broken down into three different sections: 1) design, 2) construction, and 3) operation and maintenance. Each of the following analyses are guided by the assumption that Benito Juarez moves to adopt a design/bid/build structure for RWH system funding allocation to local construction/engineering firms. Design is the first step of the rainwater system's life. In the context of Benito Juarez, the design of a system is contingent upon the approval of a system's feasibility and pre-design calculations, both of which are accomplished by a pre-screening and selection process performed by the municipality with the building owner.

In a design/bid/build contract process, the design of the RWH system is left to the contractor/engineering firm that wins the city's tenor for the project. However, as is mentioned later in the Risks and Mitigations section, it is important to define the rights of water access and limitations of each party as early as the design process. Creating transparency and detail at the beginning of the project yields the best results.

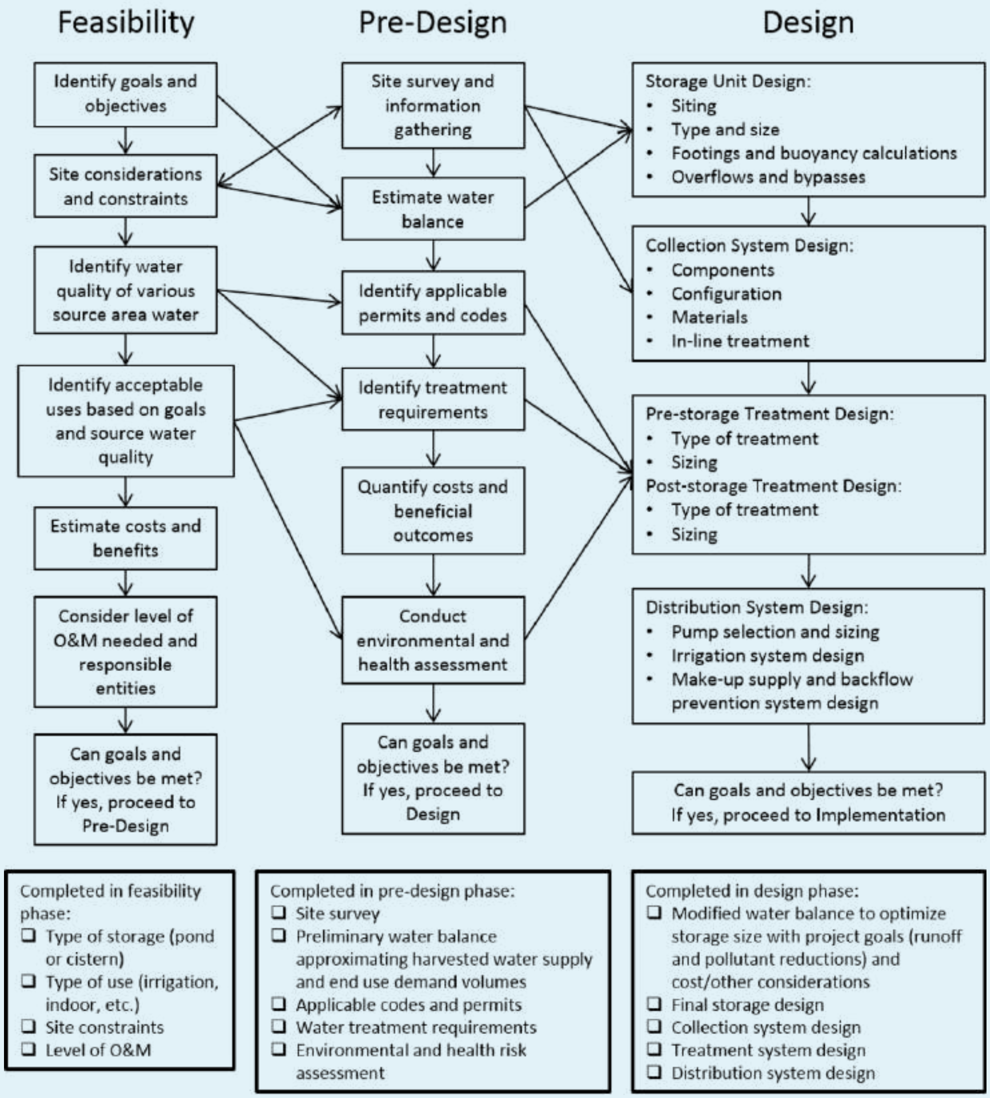


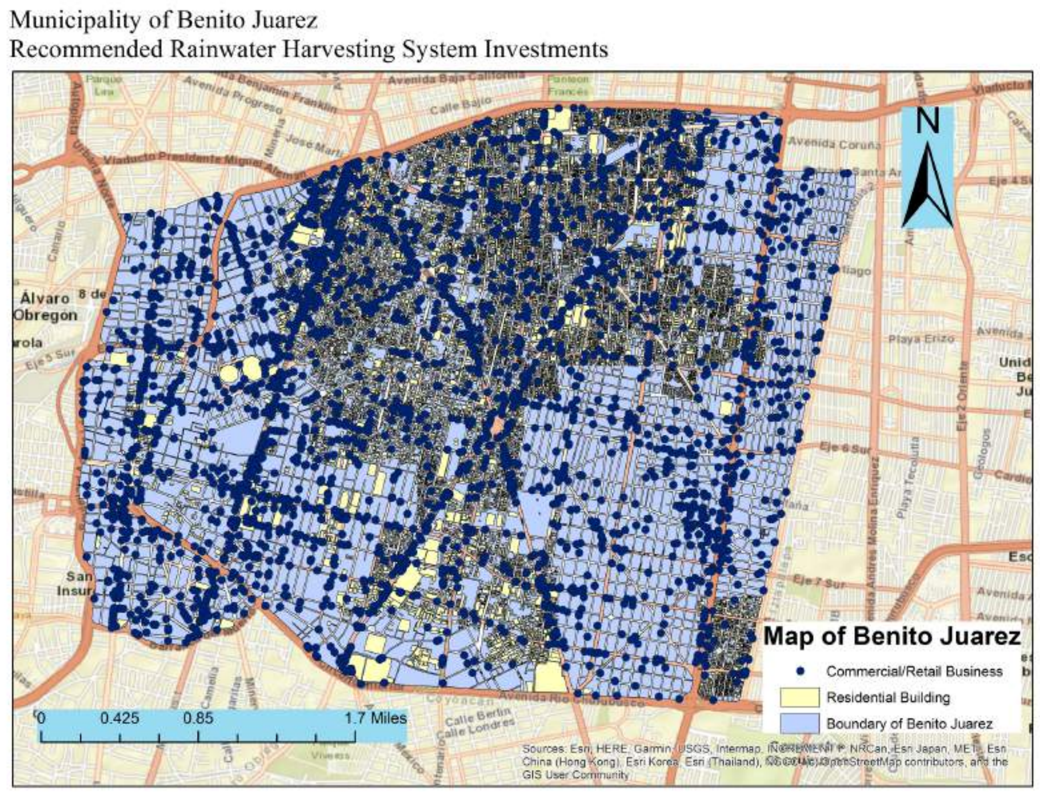
Figure 1: Minnesota State Stormwater Manual Flow Chart for Feasibility-Design Rainwater Harvesting System Process (Source: Minnesota Stormwater Manual)

Once the design is completed by the firm and approved by the city, the firm then signs into a construction contract agreement with the contractor and the building owner. As a construction agreement between all parties, this contract will act as legally binding, defining the requirements and obligations of each party with respect to the RWH system.

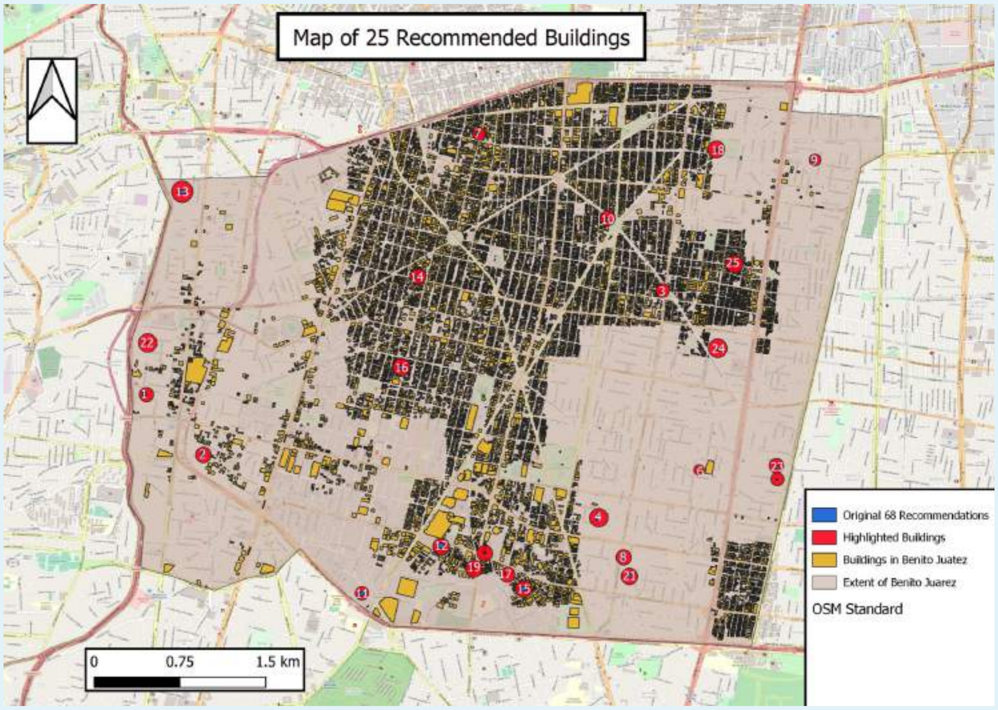
Once the rainwater system has been built, the final agreement signed is an Operations and Maintenance Agreement (O&M agreement). This agreement is the most important because it ensures that the system is maintained for the remainder of its useful life. As a standard O&M agreement, this contract will include the responsibilities of the contractor to check the system at periodic intervals to verify that it is running optimally, the responsibilities of Benito Juarez to validate that system maintenance is being done in accordance with the O&M agreement, and the responsibilities of the building owner to continue to pay their water bill and any additional charges incurred as a participatory member of the municipality's RWH policy. Specific requirements of the system's maintenance are mentioned later under the maintenance section.

Recommendations

Based on a comprehensive analysis of data provided by the Municipality of Benito Juarez, Paulina Larrauri from the Columbia Water Center at Columbia University in the City of New York and other independent sources, the recommendations for building selection come in two levels: 1) a short to medium run building selection for installation and 2) a long run building selection. Figure 2 below is a map of Benito Juarez. Note that the yellow shapes are residential units while the dark blue dots indicate commercial and retail buildings. While the dataset employed comes from OpenStreetMap, the dataset is not exhaustive.



The short to medium run building selection is based upon the Municipality of Benito Juarez's interest in 68 particular residential units within the city. While the CBA Analysis section below will provide greater detail as to the assumptions and calculations made to arrive at the top 25 buildings based on NPV, suffice it to say that the methods of calculations were rigorous. Figure 2 below shows a map view of the top 25 recommended buildings for RWH system installation. Table 1 shows this information in table format.

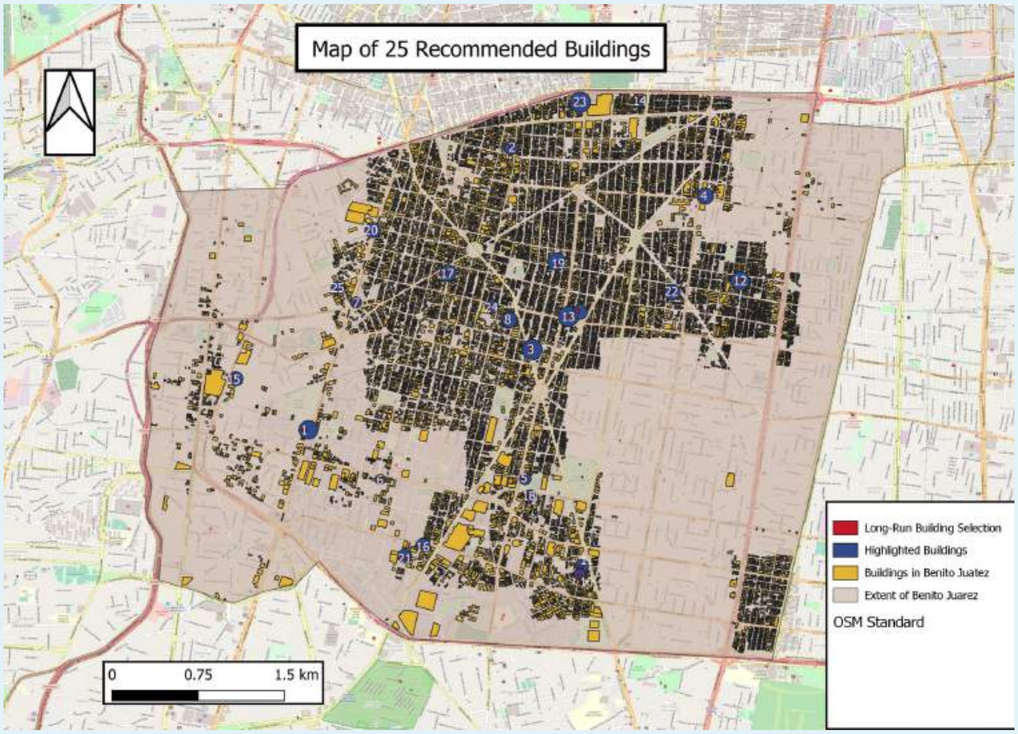


Number	building.id	area	consumption.5c	capital	NPV	Payback	IRR	Addresses
1	63	1175.18	5235	94014	202989	3.83	26%	Leonardo Da Vinci no. 113, Col.Nonoalco, C.P 03700, Benito Juárez,CDMX
2	33	1276	5684	102080	202395	4.05	24%	Campana no. 36,Col. InsurgentesMixcoac, CP. 03920 Del. Benito Juarez,CDMX
3	40	1149.84	5122	91987	201700	3.79	26%	Eje Central no. 817, Col. Narvarte Oriente,C.P 03023, Benito Juárez, CDMX
4	47	1255.44	5593	100435	199923	4.04	24%	Tokio no. 505 Col.Portales Nte 03300 Benito Juárez,CDMX
5	5	1140.02	5079	91202	199698	3.79	26%	Benito Juárez no. 89, Col. Albert, C.P03560, Benito Juárez, CDMX
6	55	1374.3	6122	109944	199593	4.29	23%	Calz. Santa Cruz no. 73, Col. San SimónTicumac, C.P 03660, Benito Juárez, CDMX
7	20	1181.26	5262	94501	199565	3.88	25%	Amores no. 43Col. del Valle Norte CP. 03810, BenitoJuárez, CDMX
8	49	1333.73	5941	106698	199353	4.21	23%	Eje Central no. 725 esq. Repúblicas, Col.Portales Sur ,C.P 03300, Benito Juárez,CDMX
9	38	1259.8	5612	100784	199023	4.06	24%	Miguel Angel 46 Col. Moderna,C.P 03510, Benito Juárez, CDMX
10	44	1390	6192	111200	198306	4.34	23%	Cumbres de Maltrata no. 787Col.Narvarte Poniente 03020 BenitoJuarez, CDMX
11	2	1051.73	4685	84138	197949	3.6	28%	Av. Coyoacan 1899, Col Acacias ,CP.03240 Benito Juárez , CDMX
12	68	1430.9	6374	114472	197887	4.43	22%	Mayorazgo de Solís no.25, Col. Xoco, C.P 03330, Benito Juárez,CDMX
13	1	1040.8	4637	83264	196854	3.59	28%	21 de Marzo no.4, Col. 8 de Agosto, C.P03820, Benito Juárez, CDMX
14	15	1076.71	4797	86137	196233	3.69	27%	Eugenia no. 618, Col. Del Valle Centro,C.P 03103, Benito Juárez, CDMX
15	29	1535.22	6839	122818	196103	4.65	21%	Paz Montes de Oca no. 39 y 45 Col. GralAnaya,CP. 03340 Benito Juarez, CDMX
16	17	1046.28	4661	83702	194732	3.63	27%	Av. Coyoacán no.1025, Col. Del ValleCentro, C.P 03103, Benito Juárez, CDMX
17	30	1584.48	7059	126758	194020	4.78	20%	Prolongacion Uxmal no. 1069 GralAnaya,CP.03340 Benito Juarez, CDMX
18	13	1629.18	7258	130334	193113	4.87	20%	Castilla no. 115, Col Niños Héroes, CP. 03610. Benito Júarez, CDMX
19	67	1706.24	7601	136499	192874	5.01	19%	Av. México Coyoacán no. 259A, Col.Xoco, C.P 03330, Benito Juárez, CDMX
20	58	1713.72	7634	137098	192629	5.02	19%	Popocatepetl no. 443, Col. Santa CruzAtoyac, C.P 033110, Benito Juárez, CDMX
21	50	1592.76	7095	127421	192607	4.81	20%	Monrovia no. 809, Col. Portales Sur, C.P03300, Benito Juárez, CDMX
22	62	1012.5	4510	81000	192399	3.58	28%	Leonardo Da Vinci no. 190, Col.Nonoalco, C.P 03700, Benito Juárez,CDMX
23	3	1670.22	7440	133618	191998	4.96	20%	Benito Juárez esq. Cda. EmilianoCarranza No. 92 Col. Albert, C.P 03560,Benito Juárez, CDMX
24	9	1024.95	4566	81996	191598	3.62	27%	Fernando Montes de Oca no. 138, ColAméricas Unidas, CP.03610. Benito Júarez, CDMX
25	51	920.46	4100	73637	187881	3.4	29%	Ahorro Postal no. 65 Col.Postal, BenitoJuarez 03410

Table 1: Top 25 Recommended Buildings for Rainwater Systems based on NPV

Source: Internal Calculation

The long run building selection is based upon the available database of buildings within Open Street Maps, an online database for spatial building references. The same assumptions that were made in the calculation of the above 25 buildings were used for these calculations as well. Figure 3 below shows a map view of the top 25 recommended buildings for RWH system installation. Table 2 shows this information in table format.



NUMBER	osm_id	Name	Building Type	Area (m^2)	IRR	NPV	Payback
1	136149197	NO NAME	0	1,186	23.70%	182,160	4.14
2	374564848	NO NAME	0	1,201	23.50%	182,072	4.17
3	526266599	NO NAME	0	1,201	23.50%	182,072	4.17
4	526543500	NO NAME	0	1,216	23.30%	182,012	4.21
5	526379200	NO NAME	0	1,246	22.90%	181,996	4.28
6	86201906	NO NAME	0	1,190	23.70%	181,845	4.15
7	406621518	NO NAME	0	1,276	22.50%	181,808	4.35
8	526360985	NO NAME	0	1,205	23.40%	181,713	4.19
9	571018676	NO NAME	0	1,175	23.90%	181,704	4.12
10	533874041	NO NAME	0	1,280	22.40%	181,447	4.36
11	526167374	NO NAME	0	1,224	23.10%	181,211	4.24
12	527139312	NO NAME	0	1,224	23.10%	181,211	4.24
13	571022323	NO NAME	0	1,269	22.60%	181,133	4.34
14	526302364	NO NAME	0	1,198	23.50%	181,105	4.18
15	672227580	NO NAME	0	1,187	23.60%	180,698	4.16
16	526184229	NO NAME	0	1,172	23.80%	180,611	4.13
17	572721582	NO NAME	0	1,172	23.80%	180,611	4.13
18	526069510	NO NAME	0	1,142	24.20%	180,582	4.06
19	526463205	NO NAME	0	1,142	24.20%	180,582	4.06
20	527524600	NO NAME	0	1,142	24.20%	180,582	4.06
21	526184255	NO NAME	0	1,161	23.90%	180,353	4.11
22	526077329	NO NAME	0	1,221	23.10%	180,333	4.25
23	526124619	NO NAME	0	1,221	23.10%	180,333	4.25
24	526165475	NO NAME	0	1,221	23.10%	180,333	4.25
25	526365207	NO NAME	0	1,221	23.10%	180,333	4.25

Table 2: Top 25 Recommended Buildings for Rainwater Systems based on NPV

Source: Internal Calculation

Cost-Benefit Analysis

In order to effectively analyze the impact of this RWH technology, we will need to conduct a Cost-Benefit Analysis (CBA). This will include comparing the pilot system (or its scale-up – depending on the information we receive) to the existing water system. In order to decide on the appropriate methodology and framework to use, it is important to look at existing CBAs that have been carried out in the Rainwater Harvesting and Water Supply spheres.

The first of these is a feasibility study that was carried out in Ethiopia by the Columbia Water Center. This study aimed to confirm that RWH was a feasible method to improve water supply and access in Dilla, a town in one of the southern districts of Ethiopia, and assess its potential financial benefits. A source and baseline analysis was performed on the existing water production mechanism, a combination of water from boreholes and surface water. This analysis found that the water authority in the city operates at a deficit since water is heavily subsidized. Another key finding was that infrastructure was inadequate, as water leakages were estimated to be more than 22% of total coverage (which is only 61.9% of the total area). The existing RWH system was analyzed, with a financial payback period of 10 years and a useful life of 20-25 years. However, existing systems were found to be poorly maintained, and poor training reduced the effectiveness and sustainability of their use. The Net Present Value was also assessed, taking into account maintenance costs, tariffs, and the expected percentage of water demand that could be covered.

The RWH system was compared to various alternatives, and recommendations and partners for scaling up the system were given. The study found that expansion of catchment areas of RWH systems could reduce payback periods, but the system was only recommended when no other water collection method besides jerrycans is available. This sheds a somewhat negative light on the utility of RWH systems. However, Dilla is a rural underdeveloped town, while Benito Juarez is a wealthier, more urban district. Thus, the conclusions of this study cannot be directly applied to Benito Juarez.

The second study conducted an economic analysis and feasibility of RWH systems in Australia and Kenya (Amos et al., 2016). Analysis of the economics of the water system was split into a comparison across countries of:

- Price of water ($/m3)
- Annual % increase in water price
- Inflation
- Interest
- Existing system's life cycle (years)
- Payback period of investment
- Net Present Value
- Levelized costs
- Cost-benefit ratio

The installation of the RWH system was a comparison across the same countries, but split into annual rainfall in mm, rooftop area in m2, tank size in m3, tank size in m3, usages of collected water (toilet, laundry, outdoor), water use in m3/person/day, reliability percentage of water collection, water savings in m3/household/year, and costs of construction, maintenance, and infrastructure savings.

The study found that water savings are the main benefit of the RWH system. The viability of a RWH project was evaluated by whether the price of water harvested would make up for investment costs. Additionally, the energy consumption of water systems was also included in the cost-effectiveness analysis of operational costs. Water systems that used pumps were found to have a higher energy intensity than other conventional systems.

Furthermore, water systems that used recycled water and RWH were found to be less energy intense.

Other benefits considered included water quality improvements due to rainwater collection. RWH was preferred to other methods of water catchment such as dams, due to certain infrastructure and absorption benefits. This was quantified through the $/year saved by investing less in other water systems and reducing the percentage usage of water mains. Additionally, RWH has secondary effects on other systems, such as irrigation and farming, thereby improving food security.

Small-scale rainwater storage facilities that were used contingently with drip irrigation systems over certain areas of land were shown to improve crop yields in kilograms/hectares. These are examples of benefits that are not directly quantified, but have been incorporated into a feasibility study. Through similar methods, we can incorporate factors such as environmental gains, climate change mitigation, or reduced flooding into our CBA. This paper also compared different methods of how to calculate rainfall yield, monthly water demand for a given number of people, and minimum tank storage.

The third paper assessed is not necessarily a CBA, but quantifies many aspects of RWH that we will be using in our own CBA in financial terms. It analyzes simplified design methods for domestic RWH in the UK, and assesses whether they are an accurate way of predicting amounts of water saved and financial results. The model uses time-series data collected on rainfall for the past 37 years. Other variables include catchment surface runoffs (water losses), coarse filter losses, storage tank losses, and water demand. Water demand was assessed by using existing water usage patterns to predict future internal and external demand for non-potable demand for newly built houses in m3/month.

Costs were also levelized in this model. The paper proposed a range of discount rates of 3.5%, 5%, 10%, and 15%, which should give us a threshold to compare to for our own CBA. The paper also pointed out that for predicted long payback periods, long discount periods are also needed, and so the method of discounting and discount period will depend on the model of our client. Monthly saving from RWH was calculated in m3 as monthly saving of water in m3 multiplied by the unit cost of water in $/m2. Monthly volume of water available is calculated:

Monthly Volume of Water Available = Average Monthly Rainfall (m/month) x Catchment Area (m2) x Runoff Coefficient (out of 1)

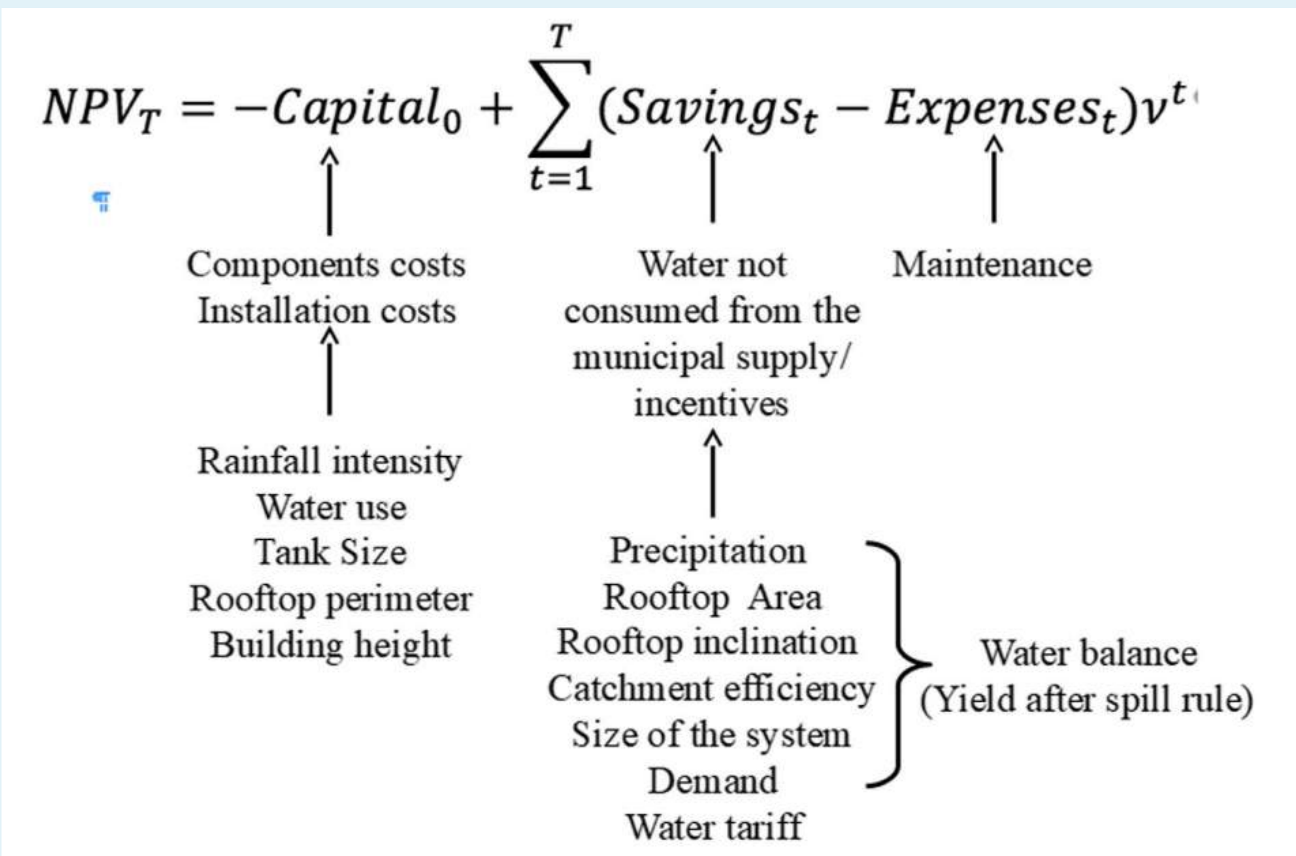
This paper was useful since it provided more equations to determine different costs and benefits. Roebuck et al. calculate water savings (main benefit) as:

Annual Financial Savings = Annual Water Demand (m3/year) x Unit Cost of Main water ($)

Another useful and extremely relevant study was carried out by the Columbia Earth Institute, assessing the financial benefits of RWH in Mexico City. The main goal of the study was to assess the impacts of rainwater variability, which sectors found RWH an attractive supplementary resource, and the effect of potential tariffs/subsidies on the potential adoption of RWH by different users. Each building was evaluated at an individual level, with the aggregate of all buildings being used as a city/borough-wide result. The study uses a Net Present Value analysis, taking into account capital and maintenance expenses, as well as current municipal tariff structures.

The paper proposed a set of benefits to stakeholders, such as policymakers, property owners, developers, water facility managers, and equipment managers. These benefits include improved access to water, reduced water supply interruptions, improved water quality, reduced flooding, and mitigation of environmental impacts. However, the study chose to focus on financial impacts only, primarily those of owners and entrepreneurs.

The Net Present Value and percentage of water demand covered with RWH are compared across building type, water use, demand, borough, roof area, water cost (capital, maintenance, tariffs), and tank size expressed as:



(Source Larrauri et al., 2020)

The model did not account for electricity costs due to the added complexity of doing so. This study has built off of previous studies where the discount period is 10 years (Roebuck et al. 2011), and so that will most likely be the discount period for our Cost-Benefit Analysis. The study also shows that a positive Net Present Value is linked to water demand and rooftop areas. Demand for RWH is calculated by adding daily water demanded covered with treated rainwater. The daily inflow of rainwater harvested is calculated as:

$$Qt = Pt \times A \times E - ft$$

- Pt = Daily Precipitation (m^3)
- A = Rooftop Area (m^2)
- E = Catchment Efficiency
- ft = daily first flush diversion (m^3)

This is similar to the calculation used by Roebuck et al., which calculates rainwater harvested on a monthly basis instead, and uses a runoff coefficient instead of E and ft. This paper also provided useful resources and data banks for Mexico City, such as the Finance Secretariat of Mexico City.

The study also provided various NPV values for Benito Juarez, our municipality of interest, for instances with subsidies/tariffs and without, across different roof areas. The average NPV was negative at varying degrees for many cases (popular tariff/no subsidy potable/non-potable), with values (either negative or positive) generally being larger for larger rooftop areas. NPV values were more frequently positive and larger for non-potable uses, and is significantly larger for non-potable uses for restaurants, small retailers, and wholesalers, and larger rooftop areas, e.g.:

Building	NPV	Area (m^2)
Restaurant	177	950
Small Retailer	383	1,900
Large Retailer	3,211	20,000

Furthermore, installation of RWH systems was found to cover 7% (41 m^2 rooftop area) -52% (500 m^2 rooftop area) of demand for domestic users.

The main conclusion of this study was that RWH was profitable for the commercial sector such as restaurants and large commercial centers, but not as financially viable for individual household use since their rooftop and catchment areas are not as large. It proposed that the government use targeted water subsidies to make RWH more economically beneficial for domestic users. Alternatively, if the subsidy was transferred and the start-up cost for the RWH system was covered by an entrepreneur, it would become attractive to more domestic users. Even in the case of subsidies, Net Present Values for domestic users were not always high, and so another proposition made by the study was networking buildings with large roof areas to provide decentralized water systems. This idea has not been tested, but is relevant to our CBA since part of the scale-up for our project can be through installing a common water reserve that is connected to multiple rooftops.

Cost-Benefit Analysis Calculations

We have carried out this CBA on a sample of 68 buildings that was provided to us by the Municipality of Benito Juarez. The methodology for our CBA was partially influenced the methodology of previous papers mentioned in our Literature Review (mainly Larrauri et al., 2020). The rest was an incorporation of our research and findings to produce our final conclusions. Our calculations for this part were conducted by using a code in R Programming specific to RWH. There are three parts in the CBA:

- Break-Even Analysis: Calculations to find net benefit (total costs – total benefits) and prove that it is positive.
- Return-on-Investment (ROI) Indicators: Net Present Value (NPV), Internal Rate of Return (IRR), Efficiency, Payback Period.
- Sensitivity Analysis: Analysis of different values for inputs and their impact on the Break-Even Analysis and ROIs. Inputs we changed included combined or individual rooftop tanks, tank size, and a suggested subsidy.

Important key parameters to consider are:

Discount Rate: 5%

Project Life (payback period): 20 years

We have modified the equations used by (Laurrari et al., 2020) for NPV based on the data we were able to access and collect. To calculate net benefit, we must obtain the difference between total costs and total benefit:

Furthermore, installation of RWH systems was found to cover 7% (41 m^2 rooftop area) -52% (500 m^2 rooftop area) of demand for domestic users.

The main conclusion of this study was that RWH was profitable for the commercial sector such as restaurants and large commercial centers, but not as financially viable for individual household use since their rooftop and catchment areas are not as large. It proposed that the government use targeted water subsidies to make RWH more economically beneficial for domestic users. Alternatively, if the subsidy was transferred and the start-up cost for the RWH system was covered by an entrepreneur, it would become attractive to more domestic users. Even in the case of subsidies, Net Present Values for domestic users were not always high, and so another proposition made by the study was networking buildings with large roof areas to provide decentralized water systems. This idea has not been tested, but is relevant to our CBA since part of the scale-up for our project can be through installing a common water reserve that is connected to multiple rooftops.

$$Net\ Benefit = \sum Cost - \sum Benefit$$

where;

$$\sum Cost = \sum Installation\ (Materials\ and\ Equipment) + \sum Installation\ (Labor) + \sum Operation\ and\ Maintenance$$

and;

$$\sum Benefit = \sum Rainwater\ Collected\ (water\ saved) + \sum Additional\ Benefits$$

Breaking these down even further:

Costs

Installation costs include both initial capital costs of material and equipment in addition to any labor required to do so. These are one-time fixed costs at the beginning of the project. Equipment needed for RWH systems generally includes: cistern, storage tank, pipes, rotoplast, filters, and other materials listed previously.

Most buildings in Mexico City already have storage tanks on their roofs to store water; however, they are not incorporated into a greater RWH system. This poses problems, since these tanks often overflow during rainy seasons and cannot provide water during dry seasons, since they cannot store any extra water beyond their capacities. Incorporating these tanks into a RWH system solves part of this issue, and also reduces a significant portion of the initial capital cost, since the tanks are already in place. Other equipment includes the remaining infrastructure for the roof, filtration system, and any modifications to the storage system.

Variable costs include the cost of maintenance and operations in the following years. These will be discounted at 5% for the project's life.Based on information that was provided to us by the Municipality of Benito Juarez, estimated costs, including capital costs, operation costs, and maintenance costs is $80 per m2 (1938.36 pesos per m2). An additional 1,000 pesos per year has been added for any additional operation and maintenance expenses.

Benefits

The main benefit of RWH is the water saved by rainwater collected, which for each building is calculated by:

Rainwater Collected = Rooftop Area x Runoff Coefficient x Amount of Rainfall + f(tank)

Rooftop area for each building was provided to us by the municipality. The Runoff Coefficient is assumed to be 0.7. Amount of Rainfall is based on meteorological data on daily rainfall that has been historically collected by meteorological stations across Mexico City. An average value for annual rainfall cannot be used, since seasonality in rainfall significantly influences water collection, water usage, and water storage, and so we use seasonal rainfall in our analysis. Rainfall data has previously been analyzed to be:

	Winter	Spring	Summer	Fall	Minimum (annual)	Maximum (annual)	Annual (average)
Precipitation	32 m^3	231 m^3	430 m^3	102 m^3	506 m^3	1195 m^3	795 m^3

Source: (Larrauri et al., 2020)

Water collected is also a function of tank size and type, and different tank characteristics have been incorporated into our calculations. We have run our initial calculations based on an assumption of 5,000 m3 tank size.

In order to represent this amount in financial terms, we multiply it by the water price that would have been paid for this water. Benito Juarez uses a tariff/subsidy system, where water price is determined by household consumption, and higher consumption warrants a higher water price. The types of tariffs/subsidies on water use are: Popular, Low, Middle, High, None; depending on whether a building is classified as domestic or non-domestic.

Thus, it is difficult to use a flat average price for water, since the only households or buildings that pay a flat rate for water are those that do not have a water meter installed, while water rates for households with a meter installed fluctuate based on consumption and tariff level. We incorporate these tariff levels based on our estimates for water consumption per building.

We were not provided data on water consumption for the buildings in our sample. However, H4O provided us with water consumption data for a similar set of buildings. We used this information to obtain an annual average consumption rate of 1,626 m3 square meter of rooftop area. This average was used to get daily water consumption rates for each of the buildings in our study.

Savings

Total savings is the monetized amount of water collected, which is the amount of water collected multiplied by water price. Average savings are 22,270 pesos/year, and total savings are 1,514,380 pesos/year.

Return-on-Investment Indicators

Net Present Value: Net Present Value (NPV) is the net benefit discounted throughout the life of the project. This means that maintenance and operation costs will be discounted at a rate of 5% for the next 20 years. The tangible and intangible benefits will also be discounted at 5% for the next 20 years. The resulting NPV is an average of 121,434.19 pesos for the 68 buildings.

IRR: IRR measures how profitable the RWH system is. The IRR value represents the return the project receives on its initial capital investment. The average IRR was found to be approximately 0.21.

Payback Period: Payback Period is how long the project takes to cover its costs and starts making a net benefit (measured in rainwater collected). The Payback Period ranges between 3.5 and 10 years, with an average of 5.66 years for all buildings.

Reliability: Reliability is basically a measure of how useful a specific RWH system is. This will be measured by calculating the total amount of rainwater collected as a fraction of total water consumption in each building i.e. how much of a building's water consumption is covered by RWH. Reliability for each season and annually is:

Winter	Spring	Summer	Fall	Year
2.51%	18.59%	33.98%	8.03%	15.83%

Sensitivity Analysis

There is some data that we were not able to collect or reach which affects the previous calculations. This includes residents or consumers per building, specific values for water consumption per building, water price, tariff/subsidy/income bracket, etc. While this data could be obtained by looking at water bills for the past year, it is difficult to do so remotely. Other missing data includes the tank size and type that will be used, since this probably has not been finalized yet, and will depend on the supplier and our recommendation.

Thus, we provided different scenarios for the results above, specifically Net Benefit, NPV, IRR, Payback Period, and Reliability, based on different values for tank size. These are 5,000 m3 and 10,000 m3. We would also like to illustrate the effects of incorporating a subsidy on RWH installation to encourage residential buildings to install RWH systems. Thus, we have also provided a sensitivity analysis on returns based on a proposed subsidy of 5,000 pesos per building.

The 68 buildings that were provided to us are split into multiple rooftops. Our initial analysis was based on considering one collective RWH system per each cluster of rooftops. We have provided a second analysis that shows returns based on installing one RWH system per each individual rooftop.

Recommendations

Building #42, UH IMSS Narvarte, has a negative NPV and very long payback period. However, the total area for this group of buildings is 22,391.42 m2, which is significantly larger than any of the other buildings in our sample. Thus, we would recommend installing a larger tank size or multiple tanks to receive higher returns for this group of rooftops.

As shown below, using a tank size of 10,000 m3 increases NPV and IRR, and reduces the payback period. Introducing a subsidy of 5,000 pesos increases NPV and IRR, and reduces Payback Period. Reliability levels with the subsidy remain the same. However, the cost to the municipality and government in this case will be higher. Using individual RWH systems per building clusters instead of one collective system increases NOV per rooftop, but reduces IRR. Reliability for each season also decreases marginally. Payback Period is almost the same. Results for each individual building and rooftop are included in the Appendix below.

Tank Size	5,000 m^3	10,000 m^3
NPV	121,434 pesos	244,830 pesos
IRR	21%	29%
Payback Period	5.66 years	3.78 years

	No Subsidy	Subsidy
NPV	121,434 pesos	181,860 pesos
IRR	21%	28%
Payback Period	5.66 years	4.58 years

	Winter	Spring	Summer	Fall	Year
5,000 m^3	2.51 %	18.59 %	33.98 %	8.03 %	15.83 %
10,000 m^3	3.21 %	25.13 %	46.63 %	11.13 %	21.60 %

	Winter	Spring	Summer	Fall	Year
Collective System	2.51 %	18.59 %	33.98 %	8.03 %	15.83 %
Individual System	2.00 %	16.27 %	30.61 %	7.09 %	14.04 %

Roadmap to Scale

ROADMAP TARGETS	ACTIVITY
PREPARATION AGREEMENT ACCEPTED BY RELEVANT AGENCIES	**ESTABLISH AN 'EXPERT WORKING GROUP'** The group should incorporate the leading engineers in implementing agency, officers in municipal government and other relevant expertises. **CREATE FEASIBLE PROJECT PLAN** By conducting field research on pilot projects and policy, and conducting an economic analysis, the 'Expert Working Group' should identify suitable buildings. Present a feasible working plan and relevant policy proposal. **ORGANIZE COMMUNICATION MEETING** Distribute communication materials to all relevant agencies and stakeholders. Hold the workshop to extensively consult. **FINALIZE PROJECT PLAN** Revise the plan according to comments until consensus is reached.
POLICY ESTABLISHMENT & FUNDS IN PLACE	**IDENTIFY POLICY GAPS** Analyze policy gaps on RWH and draft new guidelines, including 'Water quality criteria', 'RWH system installation standard', 'Maintenance regulation' and 'Emergency plan'. **ALLOCATE FUNDS** Encourage banks to lend to engineer companies. **CONTRACTING WITH ENGINEERING COMPANIES** Issue license to the qualified engineering companies. Contract with those companies.
COORDINATE WITH RESIDENTS	**MARKET THE POLICY, ENCOURAGE RESIDENTS TO USE RWH** Local borough governments should coordinate with residents and building owners to adopt RWH system
IMPLEMENTATION	**CAPACITY BUILDING** Government and relevant agencies develop the skills, knowledge, and resources of a project to improve its efficacy and efficiency. **INSTALL THE RWH SYSTEMS** Build the necessary infrastructure for RWH systems, especially electric power facilities. Then the engineering company could install the system. **MONITOR, EVALUATE AND IMPROVE** Monitor and evaluate the performance of RWH systems. Improve and make timely corrections for any problem.

Municipal Infrastructure

Water Infrastructure In Mexico City

Part of the challenge that comes with Mexico City's increase in population is the access to reliable and efficient water infrastructure. Unfortunately, many of the pipes and water infrastructure, built and installed in the 1970's, are slowly crumbling. What's more, the natural water reserves both within and without the city are at risk of drying up in as little as 30 years.

The existing infrastructure and piping networks, while effective for those with connections, have not been able to keep up with the increasing demand of the growing population. Areas in the South of the city, especially in the boroughs of Tlalpan and Milpa Alta, suffer from a lack of connectivity. This reality is forcing many to carry empty jugs to fill up from nearby wells for the day. Additionally, those who do have connections suffer from intermittent supply and leaky pipes.

The water used for everyday consumption is sourced from two main locales: 1) far away and 2) underground. According to SACMEX, the water utility company for Mexico City, water from far away is sourced in relatively mountainous regions.

The Cutzamala reservoir system for example, the largest single source of water for the city and supplier of some 30% of the city's water, is located over 120 km away from the city.

To reach the city, this water is first pumped from the Los Berros potabilization plant up to an oscillation tower. From here, it must first go through a tunnel under the Sierra de las Cruces mountain range West of the city. The transported water is then held in the Carcamo de Dolores in a series of storage tanks. Next, the water goes to a chlorination plant where it is cleaned and purified of both biological and physical contaminants. Finally, the water reaches the city where it is desperately needed. From source to tap, this whole trip can cover 2000 to 14000km of pipes through the 120 km distance. Even after all of the effort and energy used to transport this water, nearly 12% of it fails to meet drinking water quality standards.

In addition to the water sourced from the aforementioned Cutzamala system and the additional Lerma water system, the second main source of water lies underneath Mexico City. Vast freshwater reservoirs, utilized by the Pre Columbian Aztec civilization, continue to be used to this day and account for some 40% of all the water needs of Mexico City. However, the rate at which water is being drawn up from this reservoir is faster than the rate that sources like rainwater are able to replenish the supply. As a result, it is estimated that these aquifers could be depleted in 30 to 50 years. With respect to greywater and blackwater in the city, there are a number of challenges to deal with.

First, Mexico City has a combined sewer system. This means that when the city floods, fresh rainwater is channeled into the subterranean sewer system where it is mixed immediately with gray and black water, causing a surge of dirty water that ultimately goes back above ground and floods public roadways. The main challenges associated with a combined sewer system include the incidence of trash and other debris from above ground which often plug and damage the already aging infrastructure. As a direct result of this, pipes often backfill and break, leading to flooding directly into homes and other buildings in the city.

Water System In Benito Juarez

Tackling the challenges of both an inefficient and incomplete municipal water supply requires finding ways to overcome geographic and socioeconomic barriers to entry. Citizens in Benito Juarez, for example, are more centrally located to achieve connection access to a water supply. In addition, the population of Benito Juarez is primarily middle class, meaning that the affordability of the water itself is not an issue so much as a continuously aging piping infrastructure.

Specifically in Benito Juarez, this water divide means that while some receive on excess 250 liters of water per day, others are forced to survive on around 20 liters per day. The consumption of water, with data provided by the Water utility for Benito Juarez, Conagua, identifies 27% of water demand and ultimate use in the municipality is for domestic consumption, 22% percent is used for commercial and industrial services, 10% is utilized for irrigation, and 41% is lost to leaks and general inefficiencies in the municipal water infrastructure. The extremely high incidence of water lost to leaky infrastructure gives credence to the issue of aging infrastructure for many of the citizens in the municipality.

As a whole, Benito Juarez draws its water from both internal and external sources. 45% of the water in Benito Juarez comes from the Risco river, the Cutzamala system, and the Lerma drink water systems. These latter two are systems that draw water from outside of the city where the water passes through water treatment facilities for purification.

The remaining 55% of water supplied to Benito Juarez originates in groundwater reservoirs. Specifically, a series of 670 wells located throughout Mexico City at large accommodate for direct water access from the aquifer below the municipality.

In order to combat these water shortage issues throughout the municipality, the government has begun a series of small scale educational initiatives in order to educate citizens on how best to conserve water. While some recommendations include common conservation tactics such as short showers, toilet flushes only when necessary, and watering landscape vegetation sparingly, other measures include the capture and storage of rainwater by any means necessary. These recommendations do not include the installation of formal infrastructure.

Nevertheless, rainwater harvesting, a way of superseding the existing infrastructure, is an effective way of providing direct, albeit, intermittent access for all citizens in the community, irrelevant of socioeconomic status.

Rainwater Harvesting Infrastructure

Even though it is very water scarce, Mexico City receives over 700 mm of rain during the months of May to October. Much of this rainwater ends up flooding the streets and overflowing into the drainage system. Water researchers have started looking at the possibility of using this rainwater to alleviate water scarcity and slow the overuse of groundwater.

A recent Columbia Water Center study found that RWH could help address the water crisis plaguing Mexico City. Although critics often contend that RWH is not cost-effective in the short-term, the Columbia Water Center researchers used a new methodology to calculate whether the approach would yield cost savings over 10 years for specific buildings and boroughs in Mexico City and for the city as a whole. A study by a Mexican water technology company Rotoplas showed that RWH could result in positive effects for household consumers and businesses.

Many households spend a portion of their income on jugs of water, or "garrafones", in order to meet their water needs. RWH can help meet this demand and allow households to save that money or use it for other purposes. Rotoplas noted that Benito Juarez could obtain a significant amount of its water from rainwater because there are a lot of businesses with rooftops that could collect large amounts of water. Along with this benefit, the addition of RWH will ease the amount of water Mexico City has to pump from the ground.

Towns and villages in southern parts of Mexico City can also benefit from RWH, as these areas usually are not connected to the city's water system and have high water demand. The Columbia Water Center researchers collected data on local differences in water demands, water quality, rooftop areas, tariffs and precipitation. The researchers took samples of rooftop area from city maps in order to determine how much rainwater can possibly be captured.

A group of researchers from the University of Michigan also looked at the possibility of RWH to alleviate water scarcity in Mexico City. The University of Michigan study found several issues in implementing RWH.

According to the researchers, there was consensus that RWH would need to be included in a more comprehensive plan to invest in existing and new water infrastructure that would maximize the potential and efficiency of RWH. With rainwater having to be collected and transported, the state of the infrastructure is vital to the success of RWH. The group also proposed using subsidies to incentivize stakeholders to implement rooftop RWH systems in public areas to create closed-loop systems that are more cost-efficient instead of having individual RWH systems on each building. Along with this, the group also realized that the rainy season from May to October may not create enough water supply to meet demand from November to June.

23%

Lerma-Cutzamala System

67%

Aquifers

40%

Losses due to leakage

IN A NUTSHELL

- 20.1 million population & growing
- Unreliable water quality
- Poor water management decisions
- Unreliable service
- Aquifer over extraction (deficit of 6m3/s
- Only 15% of wasterwater gets treated
- Lerma-Cutzamala Electrcity (2,113 GWh/yr accounts for 86% of operating costs
- Land subsidence (10m sinking In 100 yrs)

Source: Paulina Larrauri, Columbia Water Center, Rainwater Harvesting Presentation. & Wikiwand. "Water Management in Greater Mexico City," n.d. https://www.wikiwand.com/en/Water_management_in_Greater_Mexico_City.

Institutional Analysis

Water Management & RWH Institutions

An institutional analysis is necessary to determine possible opportunities for RWH management. It is additionally helpful to address this from two angles: the institutions found within Mexico City, and general best practices found in various contexts. For example, for the latter, the following questions are relevant: what types of institutions are required to have successful RWH projects? What are common best practices found in other cities? Papasozomenou defines institutions as "the formal and informal rule systems enabling or constraining human action." Babbitt uses a more detailed definition, explaining that water institutions are "both the formal and informal practices that structure human interactions, including established rules, laws, organizational entities, norms, and codes of conduct."

According to Moglia, RWH systems have developed in three types of areas:

1. Rural or peri-urban settings without centralized water services
2. Eco-villages, where environmentally-friendly people seek out alternative lifestyles and water supply options
3. Greenfield developments in urban areas, in locations that would normally not be fully supported by existing infrastructure

In general, RWH systems do not have established rules and boundaries of ownership or management. As a result, this creates uncertainty as to who should be involved in the management, to what extent the systems should be managed or how the systems should be integrated into the existing water regime. This raises questions as to how viable RWH is for widespread or continued use. To mitigate some of this, the governance structure, including the design, planning, implementation, operation and management of RWH systems must be established. Prior to this, an institutional analysis can "set the scene".

Water institutions are especially difficult to establish because water is commonly thought of as a common-pool resource (CPR).

According to Ostrom, a CPR is a natural or human made resource that exhibits two characteristics: 1) it is costly to exclude people from using the resource 2) if one person uses the resource, it reduces the availability for others. Examples include the internet, the atmosphere or groundwater. Often, natural CPRs such as water are both depletable and renewable. As a result of these characteristics, academics argue that people follow their own short-term interests with little consideration for their long-term prosperity. If CPRs have lax management and governance structures, it becomes vulnerable to free-riding, including the overuse of the resource and no effort to maintain the resource.

Ostrom argues that in order to solve a problem involving a CPR, two things are necessary, including restricting access to the resource and creating incentives for users to protect the resource. She further argues that "no single type of property regime [or institutional organization] works efficiently, fairly, and sustainably in relation to all CPRs. CPR problems continue to exist in many regulated settings." In other words, there is no solution found in always having government, community or private ownership. That is not to say that there are no "design principles associated with robust institutions that have successfully governed CPRs for generations."

Overall, the state can either help or hinder CPR governance. For example, Ostrom states that governments can bring CPR users together in meetings, give information to help find solutions, and legitimize and enforce the solutions users agree upon. The government can also act in an ineffectual way--obstructing local organization, enforcing rules that lead to overuse, or attempting to control the resource without enforcing regulations. The economic context also plays a role in managing CPRs. For example, rising prices will encourage users to better manage the resource, whereas "falling, unstable, or uncertain resource prices" lead to worse management.

According to Babbitt, it is necessary to analyze the characteristics that drive institutional success, including "increasing populations, consumption, and advancing technologies for resource use, combined with changing markets and state policies."

Babbitt has developed 15 criteria to analyze whether a water management institution is successful. These include:

1. An ability to influence rules
2. Clearly defined water-use rules
3. Conflict resolution mechanisms
4. Benefits that outweigh costs
5. Enforcement
6. Equity
7. Flexibility
8. Funding
9. Integration
10. Knowledge
11. Leadership
12. Local control
13. Monitoring
14. Proactive planning
15. Trust

Additionally, stakeholder and beneficiary involvement is critical for institutional success. In other words, is the institution living up to expectations?

Along with these characteristics that help analyze institutional success, there are often several barriers blocking institutional change or successful water management. According to the United States Environmental Protection Agency (EPA), one common institutional barrier to RWH is optimal pricing. Often, low prices disincentivize the use of water from other sources. In the U.S., water costs rates are some of the lowest, despite extremely high rates of water consumption. More specifically, households in the U.S. will pay the same as European households annually, yet use twice as much water on average. The EPA recommends the full cost pricing of water, as this would reflect all the costs that go into water delivery, including external costs due to environmental damage or depletion.

A second barrier that limits RWH is regulations and codes. Often, codes must first be changed before RWH systems are implemented. As part of this, Western water rights are often a barrier. For[57] example, Colorado has a "first in time, first in line" doctrine that prevents RWH. This is because rain collection systems prevent water from reaching rivers, which decreases the allotted water rights of downstream users.

The EPA recommends changing these regulations, providing incentives, and establishing RWH-specific codes. Part of this means addressing health concerns with strict treatment standards for rainwater, but also lesser requirements when using water for non-potable uses like toilets.

Other recommendations include explaining required system components and educating RWH system owners on how to maximize the effectiveness of rainwater collection systems. Lastly, municipalities must review their water rates to make sure that users understand potable water is a resource with an environmental cost.

Agrawal explores the various ways in which common property institutions can sustainably govern resources. He defines successful institutions as "those that last over time, constrain users to safeguard the resource and produce fair outcomes." In order to have a successful institution, and in turn well-managed resources, there are many factors at play. Agrawal describes the need for small group sizes when governing a resource, well-defined group membership, well-defined boundaries around the resource, effective monitoring and enforcement mechanisms, past cooperation experiences and users who have physically close to the resource.

Additionally, strong leadership, the ability for users to create the rules by which to govern the resource, rules that are easy to understand, and whether the allocations are considered fair can influence whether a common resource is well managed. Lastly, market pressures will affect the management of common resources.

Because the government guarantees property rights, the role of the government is crucial to manage common pool resources. Agrawal lists five conditions that enable sustainable management relevant to governments:

- “Rules are simple and easy to understand;
- Locally devised access and management rules;
- Ease in enforcement of rules;
- Availability of low cost adjudication;
- Accountability of monitors and other officials to users.”

Dietz explains that in order for a government to have successful governance of a CPR resource, the resource must be monitored, information must be easily verified, the rates of change in the resource or technology are moderate, social capital is built, and resource users help support rule enforcement.

The challenge is that very few places in the world have these characteristics, and as such the goal is to build institutional arrangements that help build up these characteristics in some way. Dietz states that often, environmental policy ignores communities and tools such as communication, but these are important to building up the characteristics listed. Overall, Dietz suggests that the government should provide the following: trustworthy information, dealing with conflict and differences in power in order to spark learning, inducing rule compliance, providing infrastructure and technology and preparation for changes.

Berkes argues for community-based projects, but with a reservation: viewing community-based conservation as the only solution is no more effective than viewing state-based conservation as the only solution, because these both ignore the many partners required for the success of a project.

He states that full state control would only be a solution if the implementation of a project did not have social or political controversy, and if the issue at hand is very simple. As a result, Berkes states that conservation projects “cannot be conceived and implemented only at one level, because community institutions are only one layer in a multilevel world.”

In other words, CPRs must be managed with “vertical and horizontal institutional interplay.” Berkes suggests involving communities as working partners and capacity builders. He cautions against using participation as a “top-down process of co-option and consultation,” or the project will fail. To do this, the government must invest resources in trust building, mutual learning and capacity building. Richer project networks and links across organizations will lead to more successful projects.

Tortajada expands on these suggestions, encouraging local governments “to work in partnership with business communities, introducing greater transparency and accountability in decision making, developing better frameworks for long-term strategic planning, and improving public access to information and public services, all of which could lead to positive results.” However, local governments face many challenges in large metropolitan areas, including:

- A lack of coordination or communication between municipalities;
- Disjointed administrative jurisdiction;
- Financial strains;
- Opaque decision making processes;
- Lack of accountability in decision making processes.

It is important to note that several sources have mentioned communication as a critical aspect to project success. However, the UK government faced many challenges in implementing RWH, despite disseminating communication materials. Knowledge about RWH increased, but installations did not. As a result, the government realized that solely providing information does not lead to behavior change. To change this, the government produced a “Framework for Pro Environmental Behaviors”, in order to develop a targeted marketing strategy towards the public and facilitate behavior change. The government believed that policy change designed with the user’s perspective in mind will be more successful. Ward argues that strategic areas in which the government can act include “technical relevance (product development), social receptivity (capacity building), and institutional commitment (support services)”.

Papasozomenou describes three specific RWH projects undertaken in Berlin, including public, grassroots and commercial, through an institutional perspective. Often, cities select only one pilot project to analyze.

He states that cities can have multiple types of RWH projects, which can differ significantly in how they are designed, their goals, and their policy incentives. Papasozomenou uses the three case studies to demonstrate that infrastructure projects are closely connected to governance structures, and assigns the government three roles: agenda setter and initiator, incubator for change and enabler of change.

However, Papasozomenou does specify that the success of a project is also tied to socioeconomic trends, competing technologies, and the strategies of the stakeholders involved. For example, the location where the project is sited, the physical structures, the policies devised, and the economic prospects of the zone chosen will all affect the success of a project.

The first case, Berliner Strasse, describes a government project to improve public housing. The area was not chosen because there were water-related problems, but rather because the site was available close to a water protection zone. It was easy to divert rainwater from the existing sewer system. Papasozomenou explains that this project reflected the dominant worldview in Berlin at the time, that the state should be interventionist, and provide social goods.

The goal of the state was to demonstrate that social housing is compatible with environmentally friendly development, and it had funding at its disposal to achieve such a project. In this case, the state acted as the “agenda-setter and initiator,” as it was interventionist and regulatory. However, the state overlooked the difficulties in sustaining the project in the long term. After the project ended, the state did not assess how the technology affected water consumption and did not show interest in the project’s performance. On site, there was no detailing who had what responsibilities or liabilities, and as such, the system operated suboptimally.

Papasozomenou describes two other projects where the government played a different role. In one case, a planner and architect decided to build a RWH system in an old refurbished house, located in the Sonnig Wonnig community. This community had a negative public image, suffering from high levels of unemployment. The goal of the initiators was to demonstrate that environmentally friendly living could occur in real life without compromising on comforts.

The government approved of this grassroots project because it could help counter Sonnig Wonnig's negative image, attract families, and test whether RWH systems could work in a densely populated area. Prior to this project, the government had targeted this area for development, as part of Berlin's Social Urban Renewal Program and Urban Development Plan on Climate Change. As such, the government provided permits and gave some funding, in return for a legally binding agreement promise to keep rents at a certain rate. After the project was completed, it was fully functional, reducing water consumption by 85% and providing large savings on water fees. Overall, strong collaboration between the project planners, the government and residents was crucial for this project's success. In this case, the state acted as the "incubator for change," as it gave regulatory space for experimentation. However, the government has found it difficult to replicate this project in other areas, and Papasozomenou suggests better institutional support is necessary for this type of project to succeed elsewhere.

The third case Papasozomenou describes was a commercial endeavour spearheaded by IKEA Lichtenberg, who chose to install RWH systems on its store to reduce wastewater fees, promote a green image and save on energy costs. The government chose to support this project in order to make the area more commercially attractive. As a result, the government gave permits and approved construction plans. In this case, the government served as an "enabler of change". With IKEA, the government used policy in an informative manner, giving information on the various options IKEA could take regarding RWH. Everything else was up to IKEA, who was responsible for the site.

Mexico City Institutions

As aforementioned, there is a stark disparity between water availability and its demand: ten million residents living in the capital suffer from inadequate water supply, some going months without access to tap water. But the crux of the water problem Mexico City faces does not lie entirely with natural water scarcity. The Mexico City Metropolitan Area receives approximately five months of rain and flooding frequently. As such, part of the problem lies in the city's older hydraulic infrastructure and a fragmented resources management system.In order to comprehensively understand Mexico's resource management system and the viability of RWH, we must review the country's legal framework and institutional structure.

Legal Frameworks

Mexico's 1917 Constitution, enacted by the Constitutional Congress, first established the Federal government's jurisdiction over land, mineral resources, and water administration. Mexico's 1917 Constitution, enacted by the Constitutional Congress, first established the Federal government's jurisdiction over land, mineral resources, and water administration.

The document defines almost all water in the country (except rainwater) as "national water" and "when public interest requires ... the Federal Executive may regulate [groundwater] extraction and use and even specify "off-limits" zones, as well as for any other national property waters". Therefore, use is dictated through concessions or permits distributed by government agencies.

In 1992, the government passed Ley de Aguas Nacionales (LAN, or the National Water Law), with the objective of establishing an integrated, sustainable water management system that allowed for both private enterprise and public participation in the financing, construction, and operation of hydraulic infrastructure. However, it also sought to limit the exploitation of national waters by highlighting the constitutional principle that national water utilization can only be done through concessions. Hence, all distributors of national aquifers are obligated to pay service and maintenance fees. LAN was amended in 2004 to restructure the federal Comisión Nacional del Agua (CONAGUA) so it may support watershed planning and improve local participation. In 2011, access to safe, reliable water was included as a right for all residents within the Constitution of Mexico and by the Water Law of Mexico City.

Institutional Governance

From an institutional framework perspective, the responsibilities for water resource management is relegated at three levels:

1. At the federal level, the Comisión Nacional del Agua (CONAGUA) regulates the financing and supply of water resources. It also dictates the central water policy, irrigation and drainage infrastructure development, sanitation, and disaster relief. CONAGUA also manages hydraulic facilities, including the Cutzamala Pipeline, which supports distribution to the greater Mexico City Metropolitan Area.

2. At a state level, the Comisiones Estatales del Agua (CEAs) are autonomous entities that treat wastewater and provide sanitation services to their respective municipality.
3. Each municipality is accountable for the water distribution supplied by the Federal district and certain sanitation services.

Government Initiatives

According to the United Nations Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, over 100 million people will suffer from water scarcity by 2100 due to climate change.

Moreover, adaptation through reduced water use is not a viable option for many who already lack access to safe, reliable drinking water. Stable water supply is liable to various forms of discimination, including location, poverty, and gender. Moreover, poor, marginalized communities are often unable to compete for connectivity against large-scale industries and wealthier neighborhoods. Water insecurity has also been found to cause a multitude of societal, psychological, physiological, and economic repercussions.

Many academics and institutions have devoted to studying water security in Mexico, including evaluating the country's rapid urbanization, evolving socioeconomic demographics, rising demand for energy and resources, climate change impacts, and water management.

Oswald Spring studied the management of ecosystem services and scarce resources, such as water, using Mexico's various legal mechanisms and governance structures within Mexico, recommending an integrated administrative framework and participative National Water Law to ensure equity amongst varying social demographics and industries. Arreguín-Cortes et al. suggested investment by Mexico's federal and municipal governments in sustainable water management technologies.

Keepings these guidelines in mind, the government of Mexico embarked on a variety of initiatives to alleviate water scarcity in the most marginalized communities. In 2017, the Mexican government implemented the National Programme for Rainwater Harvesting and Eco-techniques in Rural Areas (PROCAPTAR) in the highly marginalized communities across eight water-stressed states. Its main objective was to improve social development, access to water and sanitation of homes in vulnerable rural areas, through RWH systems and wastewater treatment technologies at the household level.

Additionally, PROCAPTAR wanted to educate these neighborhoods on the infrastructure, its benefits, and maintenance procedures to allow for self-sufficiency. So far, 944 RWH systems have been installed.

Mexico City has also launched the Local Climate Action Strategy (ELAC) 2020-2040 and the Climate Action Programme of Mexico City (PACCM) 2020-2026 to establish a comprehensive, long-term contingency plan to combat climate[79] change. Both ELAC and PACCM emphasize the need for urban adaptation to climate change, including the adoption of widespread RWH systems.

Domestic Organizations

Several organizations—including government-funded NGOs, non-profits, and research institutes—have made significant progress towards harvesting rainwater within the country. The most prominent player is Isla Urbana, a hybrid social enterprise and non-profit, which has been installing large-scale RWH systems for rural communities since 2010. Thus far, Isla Urbana has installed over 2,600 RWH systems in Mexico, supplying 650 million liters of water to over 100,000 people in both urban and rural districts. Three years ago, the organization installed systems in select schools throughout Mexico City and launched a grassroots educational project in collaboration[81] with the International Renewable Resources Institute (IRRI) and TEMO Foundation.

The International Renewable Resources Institute-Mexico (IRRI-Mexico) strives to promote organizations that advocate a reduction in consumptive resource allocation, especially in rural and low-income communities.

As part of their Water Security Program, IRRI-Mexico has partnered with numerous RWH NGOs and water purification technology firms to alleviate water stress across five states. They also offer a variety of educational courses to community members, governments and nonprofits on best practices.

Neta Cero is another social enterprise that develops RWH systems in remote areas of the country. Founded in 2013, the organization has connected 2,315 systems in four states across Mexico, in coordination with the government's National Programme for Rainwater Harvesting. They also offer a variety of educational courses to community members, governments and nonprofits on best practices.

For the past two decades, alleviating the water scarcity in Mexico's most marginalized communities, either through legislation or subsidized RWH systems, has been the main objective for the government and local nonprofits. However, commercial and residential districts, such as Benito Juarez, have received less attention despite having a higher water demand than these neighborhoods. By increasing the water supply, RWH could be just as beneficial to Benito Juarez and mitigate its water stresses.

Institutional Suggestions for Benito Juarez

Regulations & Codes

When creating regulations and codes around RWH, governments must consider several factors. The first and most important factor is water quality. The level of water quality needed is determined by the end use of the water and the water treatments available. For example, if the water will be used for potable purposes, the risk of bacterial exposure will determine the level of treatment. The type of treatment will determine what kinds of units and how many units will be installed. Additionally, adding further treatment requirements will increase the costs of the system, an important consideration when calculating the policy's return on investment. If the municipality is not using the water for potable uses, lowering the treatment requirements will lower system costs and encourage a greater adoption of RWH.

Secondly, given that most households and municipal buildings in Benito Juarez have access to water from the tap and would use rainwater as a supplementary source, there is a risk of cross-contamination. If non-potable rainwater is integrated as a main source of indoor water use, another supply line of potable municipal water is necessary when rainwater is insufficient to meet demand (or in dry periods). This “make-up supply” carries the highest cross-contamination risk for potable municipal water. Codes are necessary in this instance, requiring a “backflow prevention assembly on the potable water supply line, an air gap, or both.” Additionally, a dual piping system may be required.

Maintenance and inspection must be considered in the context of regulations. For residential systems, RWH systems, including operation and maintenance, are the responsibility of property owners. For public buildings, RWH systems are the responsibility of the municipality. In both contexts, municipal inspections of installation, water quality and backflow prevention system inspections should be regularly conducted. For residential systems, these inspections should occur annually. For public systems, these inspections should occur on a more regular basis determined by the municipality and public building operators. Overall, using RWH systems will add to municipality responsibilities, but the level of inspection and documentation will vary depending on the context. These inspections should be integrated into the inspection department’s programming.

Previously existing codes and regulations may be barriers to RWH. For example, plumbing codes in the U.S. have been common barriers to institution RWH. Common code barriers include a lack of provisions for rainwater reuse or requiring downspouts connected to stormwater collection systems, which blocks building owners from intercept roof stormwater runoff. As a result, changing codes are often an important step in allowing RWH. Examples of successful regulations and codes include:

- The U.S. Virgin Islands have created a regulation for hotels and multi-family dwellings, stating that each dwelling must "have a minimum capacity of 10 gallons per square foot of roof area for buildings of 1 story and 15 gallons per square foot of roof area for multistory buildings."

- The city of Portland created a RWH Code in 1996, allowing the use of "dual supply systems" in residences. This allows potable rainwater to be supplemented with public water, along with a backflow prevention. The RWH Code guides homeowners on how to design and install a system.

- Washington State developed a code in 2002 for RWH in commercial facilities, requiring large cistern sizes determined by roof areas. Additionally, in 2003, Washington passed a 10 percent reduction in stormwater fees for commercial facilities that have a RWH system.

- In 2005, Texas passed a bill creating a committee that determined water quality guidelines for the use of rainwater. The committee is meant to recommend various methods for treating rainwater, how RWH systems can be used along with municipal water systems, and how Texas can successfully encourage the use of RWH.

Recommendations

1. Identify what main water uses the municipality wishes to have - potable or non-potable, indoor or outdoor water uses

2. Identify treatment standards for both potable and non-potable water, following common standards

Classification	Uses	Required quality (max. values)	Required treatment
Non-Potable	Gardening and toilets	NOM-003-SEMARNAT-1997 Fecal coliforms -240 UFC/100ml Oils and fats – 15 mg/l BOD5:20 mg/l TSS – 20 mg/l	First flush filter Leaf filter Chlorination*
Potable	Showers, personal hygiene, dishes, laundry, water for cooking.	NOM-127-SSA1-1994 Besides the previous ones pH: 6.5 – 8.5 Total coliforms – None detected/100ml Fecal coliforms – None detected/100ml Cannot exceed any of the parameters.	Besides the previous ones: 20 micron sediment filter Activated carbon (remove organic contaminants including heavy metals) 5 micron sediment filter Chlorination **

Water norms for Mexico & RWH system components.
Source: Paulina Larrauri, Presentation "Rainwater Harvesting", Columbia Water Center, Earth Institute, Columbia University.

3. Create an implementation task force to come up with the best guidelines for regulations and codes most suitable for the Benito Juarez context. This task force could be paid through various ways - entirely from the municipal budget or split between private institutions, SACMEX, CONAGUA, Comisiones Estatales del Agua (CEAs) and the municipality. If the project will focus on private commercial or residential buildings, these actors could also be incorporated into the task force and its payment. If possible, we recommend devoting a water bill line item to fund water conservation efforts, specifically RWH, and using part of this money to pay for the implementation task force.

4. When creating regulations and codes, be specific on the system components:

- Consider cistern size, foundations, location, enclosures, roof structure, capacity, materials, outlet drains, overflow, roof washers and system disinfection
- Consider water rights
- Consider electrical permits for pumping systems and other electrical controls
- Plumbing permits for RWH systems

5. Identify maintenance requirements and regularity of inspections, and who will be in charge of these elements (municipality, residents, private institution, SACMEX, CEAs).

6. Determine permitting guidelines. For example, one permitting guideline could be that all new municipal construction should consider a self-sustaining water supply system.

7. Create an operations and maintenance manual for RWH system users, to ensure that the system functions properly.

8. Create public information materials and educational programming so that regulations and codes are adequately followed. Informing the public will encourage minimal water wasting behavior and encourage the public to operate RWH systems accurately.

Financial Incentives, Tax Exemptions & Subsidies

Using financial incentives can encourage the use of RWH systems. Various cities have implemented financial incentives to encourage RWH. Examples include:

- Property tax exemptions for homeowners and commercial RWH installations. According to the Texas Manual on Rainwater Harvesting, in order for commercial users to qualify for this exemption, the Commission on Environmental Quality must first determine that the property is "used for pollution control measures". From there, the local tax appraisal district must review the applicant's documentation before giving the tax exemption. For homeowners to qualify, certain counties will provide a $100 rebate on the tax exemption application fee. If the residence is only using RWH systems as its source of water, certain countries will give a tax exemption equal to the value of the RWH system.

- Texas lets public schools, higher education institutions, state buildings and local governments to use performance contracts. This "allows a facility to finance water- and energy-saving retrofits with money saved by the reduced utility expenditures made possible by the retrofit."

- The City of Austin offers discounts and rebates to citizens. For example, the city sells rain barrels for $60, below market cost. Additionally, the city allows four rain barrels per citizen. When citizens decide to buy their rain barrels through other sources, they can obtain a $30 rebate. If citizens obtain pre-approval for a RWH system, they may receive a $500 rebate for the cost of installing the system. Commercial entities can be eligible for rebates up to $40,000. Part of the application for the rebate includes a list of suppliers, contractors and optimal tank sizes.

- The City of San Antonio also offers RWH rebates, up to 50 percent. The San Antonio Water System's (SAWS) Large-Scale Retrofit Rebate Program provides rebates for the installed cost of equipment to industrial, commercial and institutional customers. The rebate amounts are determined through various calculations, such as "multiplying acre-feet of water conserved by a set value of $200/acre-foot" and having projects remain in service for 10 years. Projects are metered in order to submit water use data to SAWS to see if conservation goals are achieved. Additionally, an engineering proposal and water audits are required to obtain the rebate. Overall, the rebate incentivizes industry to take on RWH projects because the ROI period is shortened.

- Tucson, Arizona has in place generous rebates for cisterns:
    - The rebates cover up to $2,000 of the cost. A cistern with less than 50 gallons will not get a rebate. A 51-799 gallon cistern will get a 0.25 cent rebate per gallon. An 800+ gallon will get a $1 rebate per gallon. As the tank size increases, so does the rebate.
    - People must attend a 3-hour rainwater harvesting course before obtaining the rebate—these classes are paid for by the government.
    - Studies demonstrated that the Tucson rebates resulted in a statistically significant reduction in water demand for people who use RWH systems. The demand reduction resulted in a reduction in peak summertime demand, the most expensive demand to meet.
    - Tucson works alongside private companies to deliver these services. The city provides a list of contractors and stores to buy cisterns, but they make it clear they are not endorsing any of these businesses. Unfortunately, companies often recommend that buyers obtain large tank sizes in order to get the maximum $2000 rebate, but these are not always the ideal sizes for households. In this case, the subsidy is not driving the proper behavior.
    - At a large scale, the government has mandates for new construction, requiring all new construction needed 80% landscape irrigation met by RWH. Builders found this measure cost-effective.
    - The government tracks the effect of subsidies to see how they are working using statistical econometric approaches. Sub-metering is also a good option to track the effect of subsidies.

Recommendations

Table 6.1: Definition of Subsidy Policies/Procedures among Legal Instruments.

Law	Institutional responsibility for subsidy system
	Source of finance
	Very general description of eligible group
	Very general rules to avoid creation of perverse incentives
Regulations	Detailed specification of budgeting procedures
	Detailed specification of selection procedures
	Detailed specification of payment procedures
	Process for regular evaluation and review of subsidy system
	Mechanisms to ensure coordination with tariff decisions
Contract	Role of concessionaire in administering the subsidy scheme
	Procedures for timely transfer of subsidy funds
	Procedures for billing subsidized clients
	Procedures for regulatory oversight of subsidy system

Source: Foster, Vivien, Andrés Gómez-Lobo, and Jonathan Halpern. "Designing Direct Subsidies for Water and Sanitation Services, Panama: A Case Study ." The World Bank, November 1999.

1. Use an implementation task force to come up with the most suitable financial incentives for the Benito Juarez context. Examples may include:
   a. Subsidies - either direct or to water utilities
      i. Direct subsidies are transparent, explicit and minimize water utility behavior distortions
      ii. Subsidies to water utilities are easier to define eligibility criteria and the administrative costs are lower. If doing a direct subsidy, the utility will play a critical role in identifying candidates and facilitating applications.
      iii. To lower administrative costs, the selection process for a direct water subsidy should be integrated with other subsidy schemes currently in operation (avoiding the creation of parallel bureaucracies)
      iv. If implementing a subsidy, the following must be established: the government institution with overall responsibility for the program; the sources of finance for the subsidy; basic principles that should be adhered to when administering subsidies; if private concessionaire will play a role, their responsibilities must be clearly defined in contracts.
      v. In terms of funding, public institutions must fund subsidies. They should be incorporated into the institution's budget and the service provider should be paid in accordance with the tariff.
   b. Property tax exemptions similar to those described above
   c. Sales tax exemptions for RWH system supplies
   d. Rebates similar to those described above - overall, the utility should analyze the benefits and costs of offering a rebate. The Texas Manual on RWH suggests doing this "by condensing the factors into terms of dollars per acre-foot ($/AF) and comparing that to the cost of building a new water supply project."
      i. If choosing private companies to help in this process, transparency at every step of the process is key. Rules governing the actions of the companies must be explicit. The municipality should provide a list of contractors and stores to buy cisterns, but make it clear they are not endorsing any of these businesses.
      ii. If offering rebates, the municipality should lower these over time, as cistern prices become cheaper
   e. The municipality should consider implementing RWH mandates for new construction
   f. Pay for RWH equipment through utility bill savings for commercial and industrial consumers

Installation & Set Up

According to the City of Seattle, which implemented public, residential, and commercial RWH systems in early 2009, designing and implementing RWH systems at scale requires a coordinated network of professionals, each providing their own unique expertise to the project. Such roles include:

- *Architects* to formulate and manage the design.
- *Civil Engineers* to establish connections from the RWH system to the necessary usage units and any greywater recycling systems outside of the building. They will also provide consultation on how to direct overflow for stormwater maintenance.

- *Mechanical Engineers* to install roof drainage systems, filtration/purification structures, in-building antisepsis for RWH reuse, and connection to sewage pipelines.
- *Electrical Engineers* to station pumps for underground water storage units.
- *Water Utility Providers* to contribute water pricing and quality expertise.

The second component of scaled RWH installation is selecting a systems vendor. According to the State of Delaware, "it is advisable to have a single contractor to install the Rainwater Harvesting system, outdoor irrigation system and secondary runoff reduction practices." To ensure a successful and streamlined process, many state and municipal governments follow a methodical five step process:

1. *Analyze the Project Requirements*: The RWH project management team must clearly define the scope of the implementation (including the product requirements, material quality standards, and technical mandates).
2. *Draft a Request for Information (RFI)*: The RWH project management team must publish their needs and list of baseline requirements. Responses from viable firms will help create a shortlist of potential vendors.
3. *Distribute Request for Proposal (RFP) and Request for Quotation (RFQ)*: Shortlisted vendors should be sent an RFP to complete. It should contain the full details of the RWH project, including submission details, project background and scope, system requirements, assumptions and constraints, terms and conditions, selection criteria. Potential vendors should also provide a quote so the Municipality can assess costs.
4. *Proposal Evaluation and Vendor Selection*: The project management team, in coordination with key stakeholders, must do a comprehensive review of all vendor, assign importance value for each project requirement and vendor criteria, and assign a performance value for each requirement before calculating a final weighted score for each vendor. The vendor with the highest score should be selected.
5. *Contract Negotiations*: The project management team must work closely with the vendor to define any time constraints and benchmarks. This will allow for a transparent and fair contract negotiation process.

Recommendations

1. To support the diverse individuals, small business, and tradesmen required to install RWH systems throughout public facilities, a dedicated team of project management administrators at the Municipality is required. The project management task force should be responsible for delegating tasks, organizing timelines, and tracking key milestones.
2. Developing an exhaustive Request for Information (RFI) and Request for Proposal (RFP) will facilitate the most streamlined vendor evaluation process for the project management team
3. Considering that uniformity and scale are necessary for a city-wide project, a well-established RWH enterprise with a strong performance record and proven best-practices methodology is preferable.

Maintenance

The municipality should create a maintenance and operations manual, including all of the information necessary to ensure RWH systems function properly. Information in the manual should address water quality, including how often to clean filters, remove pollutants, conduct inspections, seasonal operation and so on. The chart below addresses these considerations. The information was collected directly from various sources.

Component	Description & Cost	Effectiveness	Maintenance Actions	Suggested Frequency	Actor
Water Quality	Water must be regularly tested by a licensed operator to ensure it is safe for human consumption.	N/A	Perform water quality test; check water quality for proper chemical balance. Monitor turbidity level. Test pH, temperature, and disinfectant residual.	Daily	Owner & Qualified Third Party Inspector
Filter cartridges/Membranes	Filtration removes suspended particles from water by passing it through a permeable material. Water is pumped through the filters/membranes that must remove at least 99% of particles that are 3.0 microns or larger in diameter. This is sometimes achieved in stages with filters set up in series.	N/A	Replace filters as needed per manufacturer recommendation.	Manufacturer-specified intervals	Owner
	1) Cartridge filter - $20-60	Removes particles >3 microns	Replace filters as needed per manufacturer recommendation.	Change filter regularly	
	2) Reverse osmosis filter - $400-1500	Removes particles >0.001 microns	Replace filters as needed per manufacturer recommendation.	Change filter when clogged	
Disinfection systems - ozone, chlorination, ultraviolet radiation	Disinfection systems are capable of inactivating (or killing) viruses that might be in the water through chemical or physical means.	N/A	Ensure dosing intervals are set as needed to sufficiently disinfect the amount of water processed through the system. Ongoing monitoring is essential to achieving this requirement. Ensure chemical supply and injection system levels are adequate. Replace equipment such as ultraviolet (UV) lights at the end of their life. A UV lamp typically lasts about on year, and its effectiveness begins to diminish as it ages.	Daily; Manufacturer-specified intervals	Owner
	1) UV light disinfection - $350-1000 ($80 to replace UV bulb)	Disinfects filtered water povided there are <1,000 coliforms per 100 milliliter	N/A	Change UV lightbulb every 10,000 hours or 14 months, protective cover must be cleaned regularly	
	2) Ozone disinfection - $700-2600	Less effective in high turbidity	N/A	Frequent testing or use of monitor ($1,200)	
	3) Chlorine disinfection - $1/month manual dose or $600-$3000 automatic self-dosing system	High turbidity requires a higher concentration of prolonged exposure, can be mitigated by pre-filtering	N/A	Monthly dose annually	
Debris Accumulation on a roof - use of a Roof Washers	1) Box washer ($400-800)	Neglecting to clean the filter will result in restricted or blocked water flow and may become a source or contamination	When using a box washer, it is necessary to clean the filter after every large rain	Varies depending on type of roof washer.	Owner
	2) Post filtering with sand filter ($150-500)	Susceptible to freezing; a larger filter is best	Occasionally backwash the filter	Replace filters as needed per manufacturer recommendation.	
	3) Smart-valve rainwater diverter kit ($50)		Occasional cleaning	Resets automatically	
Catchment surface	A surface where rainwater is collected; the collection of runoff from roof surfaces.	N/A	Check for overhanging branches, animal activity, metals or chemical leaching from catchment material.	At least once every 6 months, at the beginning and end of the rainy season	Qualified third party inspector
Storage tank	Tanks can be made of plastic, metals, concrete or wood. Prices range from $0.30-$2.00 per gallon.	Pros & cons of various types of tank vary	Look for leaks, corrosion, degradation, sediment accumulation (all identified through poor system performance). If water smells bad, drain and clean. Inspect tank for sediment building, inspect structural integrity of tank, pump, pipe & electrical system components.	At least once annually	Owner & Qualified third party inspector
Conveyance elements	Rainwater is conveyed to the storage tank through a 'conveyance network.' Common methods include the use of gravity flow or the use of pumps. Conveyance networks have several components: external gutters, downspouts, drainage piping and first flush diverters	N/A	Check that there is "positive" drainage, remove debris and clogs, and check for rust or mold	Every 6 months	Owner & Qualified third party inspector
	Gutters & downspouts				
	Debris removal			Check every 3-6 months	
	First flush diverters			Check after every rainfall event to ensure there is no standing water	

Component	Description & Cost	Effectiveness	Maintenance Actions	Suggested Frequency	Actor
Decomissioning a system	Decomissioning occurs whenever a system needs to be shut down, either temporarily or permanently. Price of decomissioning varies.	N/A	Drain all rainwater in the tank & rainwater pressure piping. Shut off water supply to the make-up water system. Disconnect electical supply. Disconnect fixtures from rainwater supply and connect to potable water system.	Whenever the system is decomissioned	Owner & Qualified third party inspector

Chart was compiled directly from various sources.

Governance & Rules

Product Development

Given that RWH can provide an additional source of water to federal facilities and alleviate water stresses, many governments invest in the R&D of water-efficient technology for improved stormwater management and green infrastructure. Such ventures can take multiple forms, including providing *grants* to academic institutions or think tanks researching enhanced RWH mechanics, providing *access and data* to NGOs and nonprofits analyzing the impact of various RWH systems, and providing *scalable projects* to social enterprises looking to improve sustainability. By fostering advancement in RWH systems, the quality and efficiency of the practice will sharpen.

Despite containing approximately 18% of the world's total freshwater, only 28% of Brazil's largest metropolises have adequate water access. In 2003, the federal government funded the Programa Um Milhão de Cisternas, or "One Million Cisterns" project, to ensure all citizens had connection to a safe and reliable water source. Organized by the Articulação Semiárido Brasileiro (ASA), the scheme aimed to promote the spread of the use of water reservoirs in Brazil's semi-arid regions, specifically through the dissemination of cost-effective RWH technology. The venture empowered social enterprises and local non-profits to improve upon the rig's most elementary components: the gutter, the pipe, the pump, the sanitation equipment, and the collection basin. According to the ASA, innovations in RWH technology and implementation have led to more efficient agricultural/irrigation practices, increased livestock, and improved sanitary standards in rural communities, in addition to decreasing water stress across the grid. By October 2015, the program had successfully delivered 578,336 RWH systems and depressed costs from approximately $1250/rig to $900/rig.

Capacity Building

Capacity building refers to the process by which governments and organizations retain and improve upon the skills, knowledge, and resources of a project to improve its efficacy and efficiency. According to the United Nations Development Programme, capacity building is a long-term continuous development initiative involving stakeholders at every level (local government, relevant ministries, utility providers, non-profits, NGOs, academics, etc.) to overcome complications and hurdles in policy development, financing, implementation, communication, education, oversight, and evaluation.

In 2014, a coalition of nonprofits began a technology-transfer and market-oriented strategy using RWH to improve food security and alleviate poverty in sub-Saharan Africa. Centers for RWH research and education were established across universities in Ethiopia, Kenya, Mozambique and Zimbabwe to act as informational hubs and focal points.

The capacity building and training workshops focused on both the scientific and theoretical dimension of RWH, project management, and financing. Over the next three years, these workshops were instrumental in bridging the institutional, administrative, knowledge, and communications gaps in the initial policy.

Support Services

When a government is both the "*agenda-setter and initiator*" in a sweeping implementation, critical support services must be offered for the scheme's continued development and maintenance. For RWH projects, assistance may include routinely drafting documentation for best practices, cultivating a database of approved agencies for water quality inspection/testing, and establishing an agreement with building management for system repairs. Annual maintenance contracts and strategic repairs can offer much needed relief to the building facilities staff.

Recommendations

1. To nurture technological advances and social entrepreneurship within RWH throughout the Municipality of Benito Juárez it is imperative the government participate in R&D efforts.
2. To better achieve its mission, the Municipality of Benito Juárez should develop a comprehensive capacity building framework that works to continuously improve the technological capability, organizational capacity, cost-effectiveness, and sustainability of its RWH agenda.
3. To sustain the project over a long time horizon, the Municipality of Benito Juárez must offer institutional support services to foster continued learning, research, collaboration, and maintenance in RWH systems

Risks & Mitigation of Rainwater Harvesting

Risk		Mitigation
Financial Risk	Cost overrun	Higher liquidated damage and milestone payment Sensitivity test Sufficient project management
	Deviated cost estimation	
	Discount rate error	
Political & Social Risk	Budget conflict	Open data Marketing and educational programs
	Local NGO	
	Citizens and the community	
Water Quality Risk	Local pollution	Independent monitoring
	System contamination	Wholesome management
Policy and Legislation	Water rights	Clear language in related legislation
	Connecting to public water supply system	Establish corresponding infrastructure
	Lack of compensation	Urge for subsidy or incentives

Financial Risk

In our NPV analysis, we assumed that the cost of installation of a RWH system will strictly follow the timeline we acquired from similar projects. Thus, in our work, we left no buffer for potential cost overruns or delays. However, it is possible that the contract is delayed due to force majeure or other project management issues, such as inaccurate project estimation, errors in project design, policy change during the construction period, administrative issues and poor site management.

Additionally, it is complicated to estimate the cost of resources required into the future. This includes cost of material for pipes and tanks, cost of manpower for finding the right procurement and contractor, and cost of storage etc. Since it may take months, even years, to complete the installation for the whole Benito Juarez area, depending on the size of scaling up, it makes resource cost estimations difficult. Since the volume of the project could be quite large, a slight change in the price of aforementioned resources would cause a large fluctuation in the overall cost and the NPV. Therefore, preventive action should be taken in order to deal with the cost overrun. The discount rate of the project will vary depending on the risk and return on the project. Due to the fact that the discount rate we adopt is simply the industry benchmark acquired by studying other similar projects, it is complicated to incorporate the financial cost into the analysis.

Mitigation

Firstly, the municipality could mitigate potential project delay by negotiating a higher liquidated damage with the EPC company. Liquidated damage is a certain term on the contract that gives the municipality the right to claim damage and incurs obligation to the EPC company to shoulder the cost and revenue loss, or benefit loss in our case, if there is a delay due to reasons other than force majeure. By setting a higher ceiling, the risk of project delay can be mitigated. In addition, milestone payment, which states that proportion of payment will only be fulfilled if the certain project target is realized before the agreed time, could also provide incentives for the EPC company to stick to the schedule.

Secondly, to handle the potential change in material and financial cost, it is optimal to do a sensitivity test and see how the fluctuation would change the total cost. Based on the possibility of events taking place, it is also reasonable to put aside some funds as a buffer in the financial analysis.

Qualitatively, sufficient project management would also play an important role in mitigating financial risks related to the construction period. Building closer relationships with partners that have a good performance record would also boost the credit of the project, and thus soothe the impact of changes in the discount rate.

Political & Social Risk

Although the municipality aims to install more RWH systems in the Benito Juarez area, there could be unforeseen issues, such as budget conflicts or the emergence of higher priority plans.. Since the municipality is the key driver of scaling up efforts, its support, both politically and financially, is critical to the success of the project. Although less direct, support from higher levels of the government, including the government of Mexico City, should also be taken into consideration. Permissions and related legislative risks will be further discussed in point 5 of this section.

Outside the government structure, there are other stakeholders whose opinions should be given weight. Local citizens and the community who are going to be the end users of the system should have a say whether it is beneficial to their daily life. NGOs that support better life standards or sustainable lifestyles are also critical to municipal budgeting and development plans.

In addition, there could be unexpected social negativity. The usage of rooftop areas to build large-scale RWH systems means that there could be not enough space for other uses, such as solar panels and roof top wind turbines. Since the aforementioned two alternatives would also save energy and bring benefit to the local community, the opportunity cost of using the rooftop areas should also be considered.

Mitigation

The first and most critical method of mitigation is openness regarding the data collected and assumptions made. As such, marketing and educational programming play critical roles in communicating to the public. Without proper data publication, it is unconvincing for citizens to believe that scaling up RWH is an optimal solution that creates value.

Water Quality Risk

The quality of harvested rainwater depends on the air quality. Atmospheric water vapor can be condensed to form small droplets of suspended particles, usually called condensed nodules. Atmospheric condensed nodules are composed of solid substances, solution drops, or a mixture of the two. For clean areas, the concentration of condensed nodules are low, the air is clean, and the raindrops are slightly clean. For contaminated areas, the condensed nodules concentration is very high, coupled with the wet deposition process of pollutants. Such rainwater is dirty. While Mexico City has long been recognized as a polluted city. From 2008 to 2019, in most days Mexico City has the level of PM2.5 and PM10 suspended particles which was above the maximum healthy standard recommended by WHO.

While the concentration of chemicals in rainwater may stay within acceptable ranges, rainwater may be contaminated in the process of harvesting, storage and domestic use. Dirt blown by wind, falling leaves, insects and fecal residues from birds could all be the source of rainwater pollution. Storage tanks can provide breeding grounds for mosquitoes, including species that transmit dengue virus or malaria. Consuming contaminated water from a water storage tank can cause health risks. Therefore, the use of a strict filtration system is imperative, as well as a clean catchment area and a clean water storage tank. The system must have good sanitary conditions during use and can provide drinking water with very low health risks. Also, water quality should be managed and monitored through developing and implementing a water safety plan, which should address all components from the catchment area to the water supply point.

Mitigation

Monitoring: It is necessary to use independent surveillance to ensure the quality, safety, and acceptability of water supply based on rainwater. The main focus of monitoring, in addition to compliance verification, should be geared to assess sanitary habits during rainwater collection, storage and use, as well as improving water security. Additionally, operational monitoring should emphasize sanitary inspections. This should include inspecting the hygiene of the harvesting area and storage, the structural integrity of the system and the physical quality of rainwater like color, smell and PH.

Management: The management process should include every procedure during the operation and document corresponding data. As more and more small suppliers enter the market of RWH systems, engineering companies should help the government introduce relevant policies that dictate daily maintenance requirements and actions to take in the event of a failure. When microbial contamination is detected or sanitary inspection indicates the possibility of contamination, rainwater should be disinfected.

Policy & Legislation

Institutions may consider drafting legislation or bills to clarify when, where, and how RWH systems may be used. In addition, policy and legislation should consider how to encourage households to apply this technology and how to motivate engineering companies to enter the rapidly growing market. The following aspects should be incorporated when drafting the RWH legislation:

Water Rights: According to the 'legal definition of ownership of water resources' in Mexico: groundwater and surface water are publicly owned. They are considered the "Property of the Nation". This raises the question: if households want to harvest rainwater, would they have the right to do so?It is essential to state who has the ownership of precipitation. Although RWH laws are vague in most states of America, Colorado's law is quite clear: homeowners do not own the rainwater that falls on their property. In this example, with endless Rocky Mountains, the state uses a complex combination of 'first come, first served water rights' and riparian rights (Riparian rights is a system for allocating water among those who possess land along its path) for owners of land adjacent to the water. That is because any type of rainwater collectors "infringes on the water rights lawfully belonging to someone 'downstream". An individual harvesting rainwater would not incrementally affect the system. However, if undertaken as a collective, communities (especially those experiencing droughts) would have upset the water-allocation system. Therefore, the law should indicate clearly residents have the right to harvest rain in a given or any area.

Connecting to a public water supply system: RWH systems are similar to renewable energy systems, as they require different water supply systems to "peak-adjust", using the existing system to fill the supply gap. Because of the distinct dry and rainy seasons in Mexico, rainfall in the dry season is likely to be insufficient to provide people with enough domestic water. From time to time, people need public water systems to supplement domestic water. Therefore, relevant agencies need to clearly define how personal rainwater collection systems are connected to public water systems. When connecting a RWH system to a public water supply system, residents must inform the system developer at the time of installation and the municipality or the owner or operator of the public water supply system. At the same time, an effectively functioning water meter will help make people aware of how much water and corresponding water bills a RWH system can save households and feel its tangible benefits.

Compensation: In the literature review, we found that RWH systems have low maintenance costs and save users money when compared to faucet water, the initial costs to set up the system remain high. These costs can range from a few hundred dollars to several thousand dollars. Just like solar panels, the system could take over 10 years to recover the costs. Additionally, low income households most urgently need RWH technology to alleviate their water shortage issue. The expensive capital expenditure and long pay back period may stop some households from installing the system. Therefore, the government should consider compensating residents who are willing to place this system. Another method is providing preferential policies, like low-interest loans, to the poor for installing the system. On the other hand, typical water supply companies may encounter shortfalls in revenue due to the popularization of RWH systems. Addressing the relationship between municipal water companies and emerging RWH companies is another subject to research.

Recommendations

- Mitigate financial risk by setting higher liquidated damages and setting up milestone payments. Adopt sensitivity analysis and prepare for delay caused by force majeure.
- Provide open data to the public and keep effective communication with the public and related organizations
- Develop an efficient Monitoring and Management system, which organizes the whole process step by step, to ensure high water quality
- Define the ownership of precipitation clearly in the law
- Connect to the public water supply system and urge for compensation from the government to make the system more economically attractive

Marketing & Education for Public

Awareness

Moglia states that communities are often wary of experimental systems, including perceived health risks, potential system failure, maintenance issues and an inability to provide the same level of service as a centralized system. Another issue is that construction contractors may not fully grasp system designs, installation or maintenance, resulting in a compromised function.

In terms of RWH, the public often has fears surrounding possible health risks related to water quality. Most people drink water that is filtered, bottled into a neat pack, labeled, and sold in shops. In other words, people tend to think drinking water is equivalent to filtered water.

Moreover, when a residence is connected to the water grid and pays a low fee for water, sufficient water for low fees, they might not bother using the rainwater collected. In an interview, Marina Mautner said that many households in Benito Juarez pay a flat rate for water, even if they have RWH installed. So some people do not bother using a system they find complicated, knowing that they will pay the same rate no matter what.

As a result, new technologies need public acceptance and satisfaction in order to succeed. In order to do this, the implementer must communicate about the processes in place to prevent system failure. Key determinants of risk perception include the trust and credibility of government agencies and others involved, so messages must be consistent and honest. Additionally, fear or indifference can be assuaged through education and advertising campaigns. Texas A&M AgriLife Extension provides RWH education for the youth on basics and locations where students can see a RWH demonstration site in person. The government can also implement different water prices to simulate RWH using. While RWH may be considered an engineering task, these systems must consider local circumstances in order to succeed.

People in Benito Juarez have been obtaining their water through tap and water tanks. 54% of surveyed residents use water bottles to supplement their water supply. This behavior may be difficult to change since it is the standard way to get water. According to our survey, 37% of people have cited concerns over water scarcity. In addition, 66% of surveyed residents agree with the use of RWH systems in their homes and 82% do not believe they are hard to use. With 50% of the people surveyed not knowing how much water they use, there is a need for RWH education and water literacy.

This creates an opportunity to introduce residents to RWH and any pushback or resistance to change. In looking at the proposed expansion of RWH systems to residential areas, it is important to develop a strategy that can properly educate residents on the benefits and drawbacks of RWH. How RWH systems function can be explained to residents through a variety of mediums. We can see the results of successful RWH marketing and education in RWH systems in Germany and Singapore.

Community Meetings

A practice that we think is useful in disseminating information to the public is community meetings. Currently, when SEDEMA installs RWH systems on houses, they hold community meetings to explain RWH to the residents. This informs the residents of how RWH benefits them and how the systems function. The meetings do not only serve an educational purpose, they also create a sense of collaboration and partnership with the community. This sense of collaboration and partnership lets the community know that SEDEMA will continually work with the community to make sure that their systems are functioning and that SEDEMA will be there to assist them with any issues that they experience. Whoever Benito Juarez partners with to install the systems will need to build this relationship with the community. The Municipality of Benito Juarez will have to facilitate these relationships between the community and the company installing the systems.

Training on How to Use RWH Systems

Another critical aspect of expanding RWH systems to residents is educating the community on upkeep and maintenance. For residents installing the systems, the training should be compulsory. Engineers from the municipality or the RWH company can work with the residents to do these trainings. The maintenance of the system becomes the responsibility of the residents so engineers from SEDEMA inform residents on how to clean and maintain their systems. In addition to this, SEDEMA engineers check in on the residents to see how residents are doing with their systems. This need to communicate will need to be made at community meetings so that residents know that they have continual support from the government and RWH organization.

Pamphlets & Social Media

Creating pamphlets and social media outreach can be two effective methods to educate the public on RWH. With a significant amount of Benito Juarez's population being over 30, small pamphlets detailing RWH and how it can impact them can be helpful on its environmental, ecological, and social effects. Pamphlets should include 5 main points: 1) facts about annual rainfall in Mexico City, 2) information on how projected water savings from rainwater, 3) how RWH works 4) how RWH can help alleviate water scarcity 5)average water consumption of people in Benito Juarez. People in Benito Juarez have been receiving water through the same systems for years and may be accustomed to it. This is not a negative aspect, just an important facet to note that it may take some time for people in Benito Juarez to adapt to the new RWH systems. As younger people begin to move into Benito Juarez, a social media campaign on Twitter and Instagram can be helpful in getting the word out. Younger people use social media more as their primary source of information. Information also spreads faster on social media and this can benefit awareness for RWH.

Focusing on environmental responsibility and sustainability is vital to a successful marketing and education campaign for RWH systems. All of the municipalities in Mexico City operate as a single grid. This single grid concept generates a zero sum game for water: one municipality using less water allows more water for another. With water in Benito Juarez not being as scarce as in other parts of Mexico City, RWH in Benito Juarez can help address water scarcity in other municipalities.Since all municipalities get water from the Cutzamala and Lerma systems, the less Benito Juarez uses, the more there is for the more water scarce municipalities. Furthermore, younger people may respond better to sustainable ways of living compared to older residents who are more comfortable with receiving drinking water via groundwater extraction or water trucks.

Recommendations

- Use a three-pronged approach (community meetings, RWH system training and pamphlets and social media) to collaborate with and educate the community on the benefits of RWH systems.
    - *Community meetings*: Have a representative from the municipality of Benito Juarez and 2-3 engineers from the RWH company to explain RWH to residents whose roofs can qualify for RWH systems
        - Have meetings for larger groups of the community that want to know more about RWH
        - Document successful RWH projects in water scarce areas in Brazil, Argentina and Chile
    - *Trainings*: Use presentations, documentation, and other visuals to show residents how to maintain RWH systems
        - Clearly outline what responsibilities are the residents' and which responsibilities are the RWH company, with the Benito Juarez government acting as the liaison between the two actors
        - Mandatory trainings for residents
    - *Pamphlets and Social Media*
        - Design a simple and eye-catching pamphlet than can give a quick overview of RWH and contact information to the municipality government → aimed toward older residents of Benito Juarez
        - Create a social media campaign on Facebook, Twitter and Instagram to quickly spread information on environmental sustainability and RWH → aimed toward younger residents moving into Benito Juarez
        - Position Benito Juarez as a leader in environmental sustainability and water → create stickers, bottles, reusable bags for residents

Case Studies

Case Study 1: Reliability and Cost Analysis of Rainwater Harvesting Systems in the Peri-Urban Regions of Greater Sydney, Australia

Background

Hajani states that RWH has become popular in Australia due to three reasons, including environmental awareness, droughts and government subsidization of systems. In urban areas, RWH is used mainly to save water, giving flexibility when water restrictions are put in place. In peri-urban regions, defined as "areas having a metropolitan area on their inner boundary and a rural area on their outer boundary", RWH is used for drinking, washing and many other uses. Additionally, RWH in peri-urban areas requires a higher reliability to meet demand at any point.

This study, conducted in 2014, explores various tank sizes to determine reliability, or "the proportion of days when a RWH system is likely to meet the required demand." Hajani explains that a large RWH tank misuses resources and space, whereas a small tank may lead to water shortages. As a result, the optimal tank size depends on the amount of rainfall and the needs of households, which will change in different areas. The study considers ten locations throughout Greater Sydney, using rainfall data collected from the Australian Bureau of Metrology.

To determine the performance of the systems, the study uses a "water-balance simulation model on daily time step" using FORTRAN, a computer programming language. The model looked at rainfall statistics, water demand, tank size, losses and tank spillage. Hajani defines spillage as "overflow from the tank if the tank capacity was exceeded."

The study looks at three different combinations of water use, including irrigation, toilet and laundry and a combination of the three. Additionally, eight different rainwater tank sizes are used, all considered above ground and made of polyethylene. Lastly, the study used one site area (450m2)with three different impervious areas(200m2,150m2,100m2)- essentially, the size of a single household with four occupants.

Case Study 1: Reliability and Cost Analysis of Rainwater Harvesting Systems in the Peri-Urban Regions of Greater Sydney, Australia

Figure 1. Ten selected locations in the Greater Sydney regions.

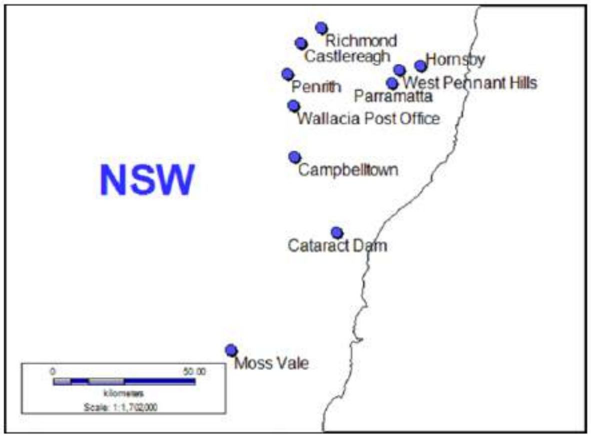


Table 1. Study locations and details of selected daily rainfall data.

Location	Rainfall station	Period of rainfall record	Average annual rainfall (mm)
Campbelltown	068007	1900–2009	743
Hornsby	066158	1936–2009	1325
Parramatta	066124	1966–2009	964
Penrith	067084	1970–2009	940
Richmond	067021	1902–2003	801
Castlereagh	067002	1950–2010	802
Wallacia Post Office	067029	1946–2010	870
West Pennant Hills	067098	1946–2005	1076
Moss Vale	068195	1972–2008	1104
Cataract Dam	068016	1936–2009	1108

Source: Hajani and Rahman, "Reliability and Cost Analysis of a Rainwater Harvesting System in Peri-Urban Regions of Greater Sydney, Australia."

The researchers conducted a life cycle cost analysis (LCCA), using data on the costs of RWH found from rainwater tank suppliers in Sydney. Capital costs included: "rainwater tank, concrete base, pump, first flush, pump to tank connection kit, electrical and plumbing supplies and all the necessary labor costs." The study used the following:

- A maintenance cost of AUD20 per year
- A water cost of AUD 2.13/kL
- A base year of 2013
- A lifetime of 40 years
- A discount rate of 3 percent

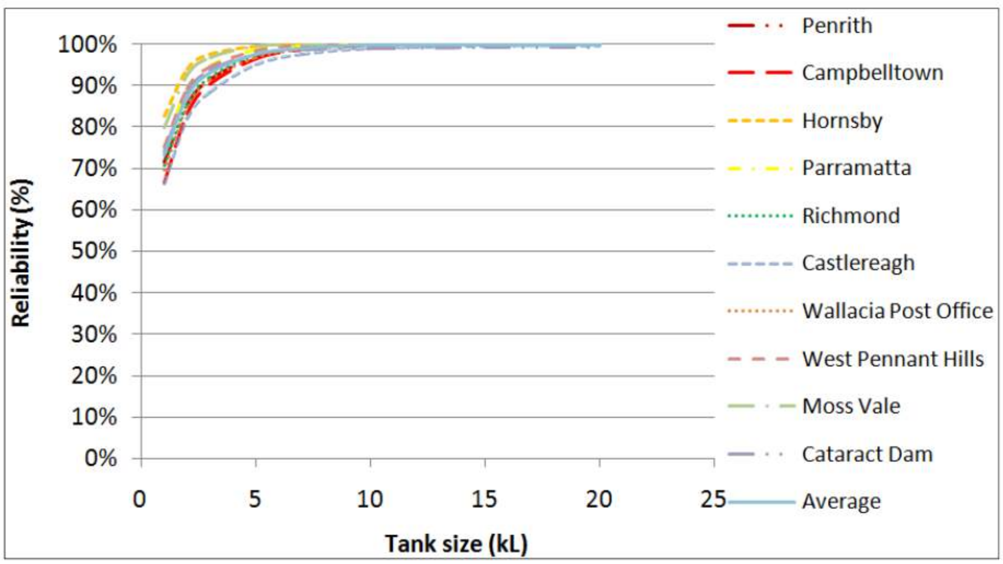
Case Study 1: Reliability and Cost Analysis of Rainwater Harvesting Systems in the Peri-Urban Regions of Greater Sydney, Australia

Findings

The study's findings show "that a 5 kL tank can meet 96% to 99% of the demand for toilet and laundry use depending on the location in Greater Sydney regions." In a dry year, this decreases to 69% to 99% depending on the location. Through the use of LCCA, the study found that a 5 kL tank "has the highest benefit–cost ratio (ranging from 0.86 to 0.97)" out of the eight sizes tested. In the scenarios conducted, the Sydney water price was too low to obtain a benefit-cost ratio higher than one. If water prices increased, the benefit-cost ratio would be greater than one. The study recommends for a combined use (irrigation, laundry, toilet) 5 kL tank, the water price should increase by 3 to 16 percent. As such, a RWH system is not financially feasible with the water price in place. To increase the use of RWH, the study finds that the government should give a subsidy to homeowners. Overall, the study divides its findings into three sections: reliability, water savings and benefit-cost ratios.

- The result shows that reliability varies significantly across different locations, which is probably due to level of rainfalls in the given areas. In addition, the level of reliability is not correlated to the size of the tank in a linear way. Instead, the slope of benefit and increase per size addition almost flattened, which indicated that the marginal benefit of tank size higher than 5 kL is too low.

Figure 3. Reliability of RWHS at ten selected locations using rainwater for toilet and laundry use (considering the daily rainfall data of all the years on record).



Source: Hajani and Rahman, "Reliability and Cost Analysis of a Rainwater Harvesting System in Peri-Urban Regions of Greater Sydney, Australia."

Case Study 1: Reliability and Cost Analysis of Rainwater Harvesting Systems in the Peri-Urban Regions of Greater Sydney, Australia

- From the data analysis, the conclusion can be drawn that after about a 7 kL tank size, the water savings become nearly the same for all ten locations. This is due to the fact that, at a certain point, the number of users in the house became the determining factor of water utilization; even if the tank becomes larger, the water savings would not increase if the number of users is not increased, “as a significant portion of the harvested water would remain unutilized."
- The table below shows the relationship between water price and Benefit-Cost Ratio (BCR). The data of BCR is calculated based on a 5kL tank size and for combined use. It indicates that the current water price of AUD 2.13/kL is not enough to make the RHS financially attractive. The price has to be increased to AUD 3.2/kL, or the equivalent through subsidies, to support a BCR higher than 1.

Table 8. Increased water price to achieve a benefit–cost ratio (BCR) close to 1.00 (Hornsby).

Tank size (kL)	Toilet and laundry use		Irrigation use		Combined use	
	Water price (AUD/kL)	BCR	Water price (AUD/kL)	BCR	Water price (AUD/kL)	BCR
1	3.48	1.001	5.72	1.002	3.20	1.001
2	3.69	1.001	4.07	1.001	2.85	1.002
3	3.77	1.001	3.32	1.002	2.52	1.001
5	4.05	1.002	2.67	1.001	2.21	1.003
7	5.37	1.001	3.02	1.004	2.54	1.001
10	6.01	1.002	2.88	1.001	2.48	1.003
15	8.32	1.001	3.37	1.001	2.93	1.002
20	10.97	1.001	3.99	1.001	3.49	1.002

Source: Hajani and Rahman, “Reliability and Cost Analysis of a Rainwater Harvesting System in Peri-Urban Regions of Greater Sydney, Australia.”

Conclusion

This study incorporated several elements we are highlighting in our project, including but not limited to tank design, water saved, types of water usage and cost-benefit analysis. By studying this case, we had a general picture of how a similar analysis could be conducted and further improved to adapt to Benito Juarez.

As our project requires a cost-benefit analysis, we can learn from this case regarding their quantitative breakdown. In addition to water saved and energy saved, we could also pay attention to the fact that utilizing a RHS would increase the reliability of water supply in Benito Juarez. While it was hard to quantify reliability, the formula and model used in this case, which is calculated by the number of days demand is fulfilled, provided us a method to translate the concept into numbers.

Case Study 2: Financial Benefits of Rainwater Harvesting in Mexico City

Background

In this second case, the financial attractiveness of RWH in Mexico City was assessed borough by borough, with our target destination, Benito Juarez, included. The paper is published in the year of 2020, which provided a closer look at the most updated status of RHS in Mexico City. Specifically, the case provided a general picture of the financial insights of RWH in Mexico City and provided detailed modelling for us to refer to.

Although all the locations and most data collected in this case are real-life figures, the study is a hypothetical analysis where potential financial benefit of RHS is assessed. The purpose of this study is to support the conclusion whether it is financially viable for Mexico City to deploy RHS as an alternative source of water supply across boroughs and sectors.

The study did a Net Present Value (NPV) analysis based on the cost and water saved of installing a RWH unit in the area. By conducting the NPV analysis, the study is able to tell whether the installation is creating value to the community. It compared the cost and benefit of installing the system and discounted the latter in order to integrate the opportunity cost of the investment. The analysis highlighted the significance of tank size, local tariffs, type of water usage and level of demand. In general, the study looks at the benefit of each year calculated by Water Saved times unit Water Cost. The former is further broken down to Daily Demand and Water Inflow. Regarding the discount rate, the study referred to the commonly used number for RWH without detailed explanations. The cost, on the other hand, covered the life cycle of the system from installation to regular maintenance.

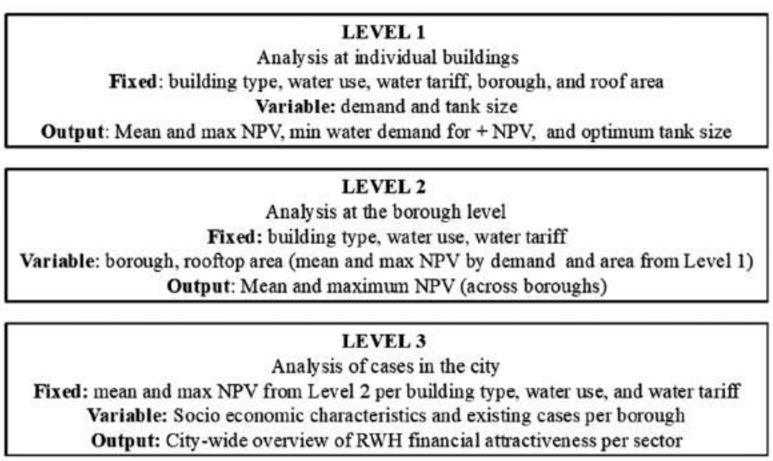


FIGURE 1. Levels of aggregation in the bottom-up approach. NPV, net present value; RWH, rainwater harvesting.

Source: Larrauri. et al., "A City Wide Assessment of the Financial Benefit of Rainwater Harvesting in Mexico City"

Case Study 2: Financial Benefits of Rainwater Harvesting in Mexico City

Findings

The result suggests that, in general, NPV would be positive under certain subsidies from the government for non-potable water usage. This is probably due to the cost cut-down for non-potable water. In addition, NPV for small and large retailers and wholesalers shows the highest financial attractiveness due to larger roof area available.

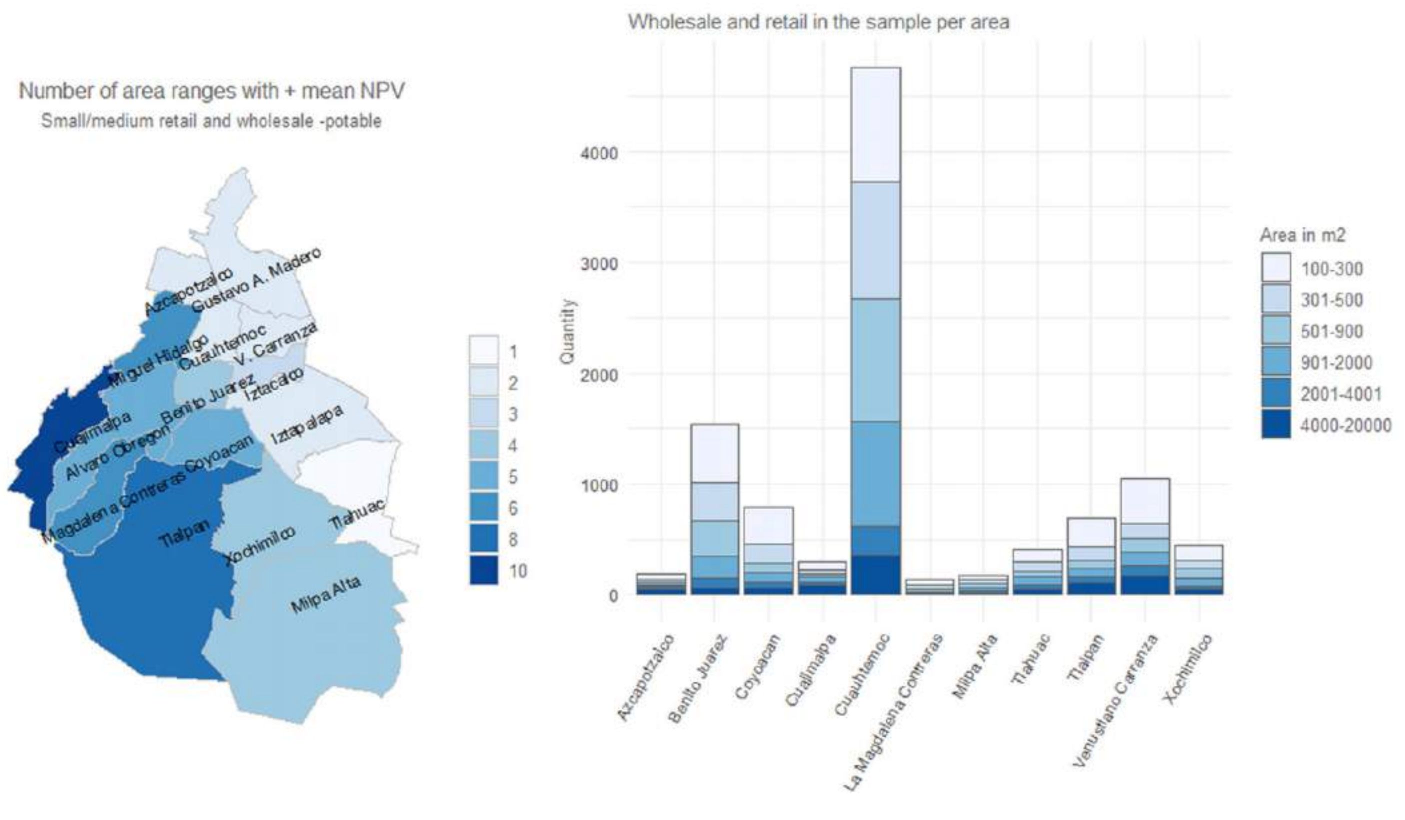


FIGURE 19. Level 3 results for all retail and wholesale. Number of rooftop area ranges with positive NPV (left) and distribution of rooftop areas in the sample per borough (right).

Source: Larrauri. et al., "A City Wide Assessment of the Financial Benefit of Rainwater Harvesting in Mexico City"

For domestic users, the demand of potable water required to support a positive NPV is high without extra tariffs. Especially for areas where rooftops are smaller than 143 m3, it is generally financially unfeasible for the system to create value for that mean NPVs are negative in almost all boroughs. On the other hand, the result of nonpotable water is showing a slightly better financial performance in wealthier areas where the need for irrigation is higher. In this case, the mean NPV demonstrates higher attractiveness as well.

Case Study 2: Financial Benefits of Rainwater Harvesting in Mexico City

For non-domestic users, NPV are more driven by precipitation and less by demand as in the analysis of domestic users. Among the non-domestic users, the category of large retailers and wholesalers demonstrated the highest level of financial attractiveness, whose demand is somehow often ignored by policy makers when designing local RWH systems.

Conclusion

Since our target area of Benito Juarez is included in this study, we obtained some secondary data for our own project from the case. By understanding this case, we had a better quantitative idea of how the size of roof areas and local subsidy policies would affect the feasibility of RWH in Mexico City. The way this case differentiated types of water usage is different from the previous case study, and it is more detailed by further dividing demand of a certain sector into potable and non-potable water. Together with its hierarchical approach, it provided us with a unique method of conducting such studies.

We could also adopt the method of NPV used in this case and add up other elements such as reliability, tank design and community awareness and build an improved model. NPV is one of the most adopted models in analyzing the financial feasibility of a project. By learning from this case, we see how we can incorporate such methods in our cost-benefit analysis and provide go or no go suggestions in a clearer way. In other words, if we can prove that a larger scale of RWH in Benito Juaraz would create value with a positive NPV, it is convincing that both the local government and the community should support the expansion.

Case Study 3: Quality of rainwater harvesting system in Colombia

Background

In 2015, a study analyzed RWH water quality in urban Colombia in order to support the conclusion that rainwater should be treated as an important source of water in the area. While it is hard to determine the quality of a RWH system, this case evaluated the quality of RWH systems in Colombian urban areas with 4 variables: roof material, material deposits, piping material, and amount of precipitation. In addition, it incorporated the influence of tank design as well as local environmental conditions.

Six buildings were selected to conduct the study. Among the 6 RWH systems, only one of them had a large-scale underground water tank with 100 m3 capacity. The study purposely selected a variety of building types covering educational, industrial, commercial and residential areas, to be more comprehensive regarding the quality needed for different water uses.

Types of buildings	Code	Number of installed storage tanks	Storage capacity (m^3)	Tank material	Roof materials
Educational building (E)	A	2	2	PVC	Asbestos cement
	B	1	1	Concrete	Metal-coated mineral fibre
Industrial building (I)	C	2	12	PVC	Asbestos cement
Commercial building (C)	D	1	100	Concrete	Asbestos cement
Residential building (R)	E	1	0.25	PVC	Asbestos cement
	F	1	0.2	High-density polyethylene	Asbestos cement
Total	6	8			

Source: Tito Morales-Pinzo, Manuel Carlderon, and Maria Garcia, "Quality of rainwater harvesting in urban systems: Case study in Colombia"

Water samples were collected from the storage tanks and later were analyzed at laboratories in Environmental Chemistry and Food. The parameters recommended by the World Health Organization and Colombia Decree 475 were used when testing the quality of the drinking water:

- Concentration of bicarbonate
- Total Organic carbon
- Chloride
- Total harness
- Soluble reactive phosphorus
- Nitrates
- Nitrites
- Ammonia nitrogen
- Total suspended solids
- Sulphates
- Arsenic
- Heavy metals

Case Study 3: Quality of rainwater harvesting system in Colombia

Findings

The study demonstrated positive results in general. The water collected was of acceptable quality, with a pH ranging from 7.6 and 8.4, low concentration of heavy metals detected, turbidity lower than 2.0 NTU and no coliform or helminth eggs detected. The study suggests that the local government take further steps towards building more RWH systems based on such results.

However, the higher-than-usual pH, according to the study, is due to the concrete used to construct the tank, which dissolved during storage. The high turbidity in building E could also be explained by similar situations. The unacceptable water quality may be a result of particles coming in without sufficient filtering or suspension of sediments.

Physico-chemical parameters	Unit of measurement	A1	A2	C	D	E	F	B	Ranges WHO
pH	upH	8.4	7.6	8.2	8.1	7.8	7.9	7.7	
Conductivity	(uS/cm)	0.05	0.06	0.01	0.18	0.03	0.03	0.1	
Heavy metals									
Cadmium	mg/l	<0.15	<0.00019	<0.15	<0.00019	<0.00019	<0.00019	<0.00019	0.003
Copper	mg/l	<0.20	<0.05	<0.20	<0.05	<0.05	<0.05	<0.05	2.0
Plumbum	mg/l	<0.50	<0.01	<0.50	<0.01	<0.01	<0.005	<0.005	0.01
Zinc	mg/l	<0.10	<0.05	0.31	<0.05	<0.05	<0.05	<0.05	3.0
Others									
Total alkalinity	mg/l	n.d	23.2	n.d	34.0	14.3	22.0	24.0	
Total hardness	mg/l	30.6	24.0	13.8	54.0	12.0	22.0	48.0	
Sulphates	mg/l	7.82	<11.0	<5.0	34.0	<11.0	<4.5	33.0	500.0
Turbidity	NTU	n.d	1.01	n.d	1.38	2.34	1.68	0.85	
Total coliforms	Counts/100 ml	0	0	0	0	0	<2	<2	0.0
Helminth eggs	Helminth eggs/L	0	0	0	0	0	0	0	0.0

Source: Tito Morales-Pinzo, Manuel Carlderon, and Maria Garcia, "Quality of rainwater harvesting in urban systems: Case study in Colombia"

Conclusion

From this case, we learned that there are a variety of storage capacities adopted in existing RWH systems. To control the cost, it is possible to build a single capacity where buildings are connected to the capacity, or have distributed storage with smaller capacity. Having a better performance in the cost-benefit analysis cost control is one of the keys to success in our case. Exploring alternative tank design and adopting the most suitable with limited resource cost would be among the first steps in our project.

In addition, the material of roofs and tanks may affect the water quality significantly. We should take that into consideration when we are analyzing water usage as well as the benefit of a RWH system. In this case, the highest level of parameter requirement, which is the level of drinking water. In our case, we could develop categorized criteria to fit the need of different water usage.

Conclusion

Installing RWH systems throughout the Municipality of Benito Juarez, including all public, residential, and commercial buildings, can dramatically reduce the water stress faced by neighborhoods across the grid. Based on a questionnaire survey with over 400 households, residents are enthusiastic towards RWH installations in their communities, believing it can considerably reduce their water price and resolve any intermittency issues. However, marketing material must be distributed by the government to educate the general public on the RWH project's environmental, ecological, and social benefits.

To successfully scale RWH throughout the Municipality of Benito Juarez, a strong institutional governance structure must be established. A dedicated "RWH Working Group", consisting of policymakers, architects, engineers, and utility providers, must coordinate together to establish the necessary water regulation, institutional framework, and governance structure. Additionally, they must hold a public tender to select a vendor that uses high-quality materials without compromising cost-effectiveness and meets all other requirements.

A cost-benefit analysis can help determine the most optimal buildings, materials, and technology to select. Rooftop area, water consumption (demand), water tariffs, initial capital costs, operation & maintenance and additional costs, and tank size were factors used in our calculations to find Net Benefit, NPV, IRR, and Payback period. Through this, we were able to give a recommendation on the buildings with the highest return ratios in the sample that was provided to us by the municipality, as well as a larger sample of buildings across all of Benito Juarez. In addition, by using different capital costs, tank sizes, and subsidy options in our analysis, we were able to calculate different return ratio values for each building based on different scenarios.

Generally, we can conclude that the installation of RWH systems provides a return in the long-run, after at least 5 years. Using a larger tank size provides higher returns on average. Similarly, introducing a subsidy provides a net benefit to residents, but may impose larger costs on the government. However, subsidies can act as an important tool to incentivize residents and building owners to install RWH systems. Finally, in most cases, having one RWH per rooftop increases the NPV for each building, but reduces the overall profitability of the project.

Overall, RWH is a worthwhile investment that can exponentially decrease the amount of water stress, price, and scarcity faced by both the Municipality of Benito Juarez and other districts in Mexico City.

Acknowledgements

This report would not have been possible without the advice and contribution of others. Our sincere gratitude to:

- At Instituto de Ecología, UNAM, Bertha Hernández Aguilar for conducting firsthand research in Mexico City on our behalf.
- At the Earth Institute in Columbia University, Paulina Concha Larrauri for her instruction on water resource management, rainwater harvesting and its unique costs in Mexico City.
- At the School of Geography and Development, University of Arizona, Dr. Elizabeth Tellman for her expert advice and feedback.
- At La Secretaría del Medio Ambiente (SEDEMA) de la Ciudad de México, Alejandra Lopez Rodriguez for expertise on rainwater harvesting engineering and guidance.
- And Dr. Erik Porse at California State University, Sacramento, Dr. Christina Babbitt at the Environmental Defense Fund, Dr. Jeffrey Shrader at Columbia University, Marina Mautner at the University of California, Davis, Tirian Mink at Neta Cero, Gary Woodard at Montgomery & Associates, Gerardo de la Garza and Isla Urbana for sharing their knowledge, research and experience with us.

Finally, we would like to extend a special thanks to Daniel Shemie, our Faculty Advisor, for his leadership, guidance and encouragement throughout this project.

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