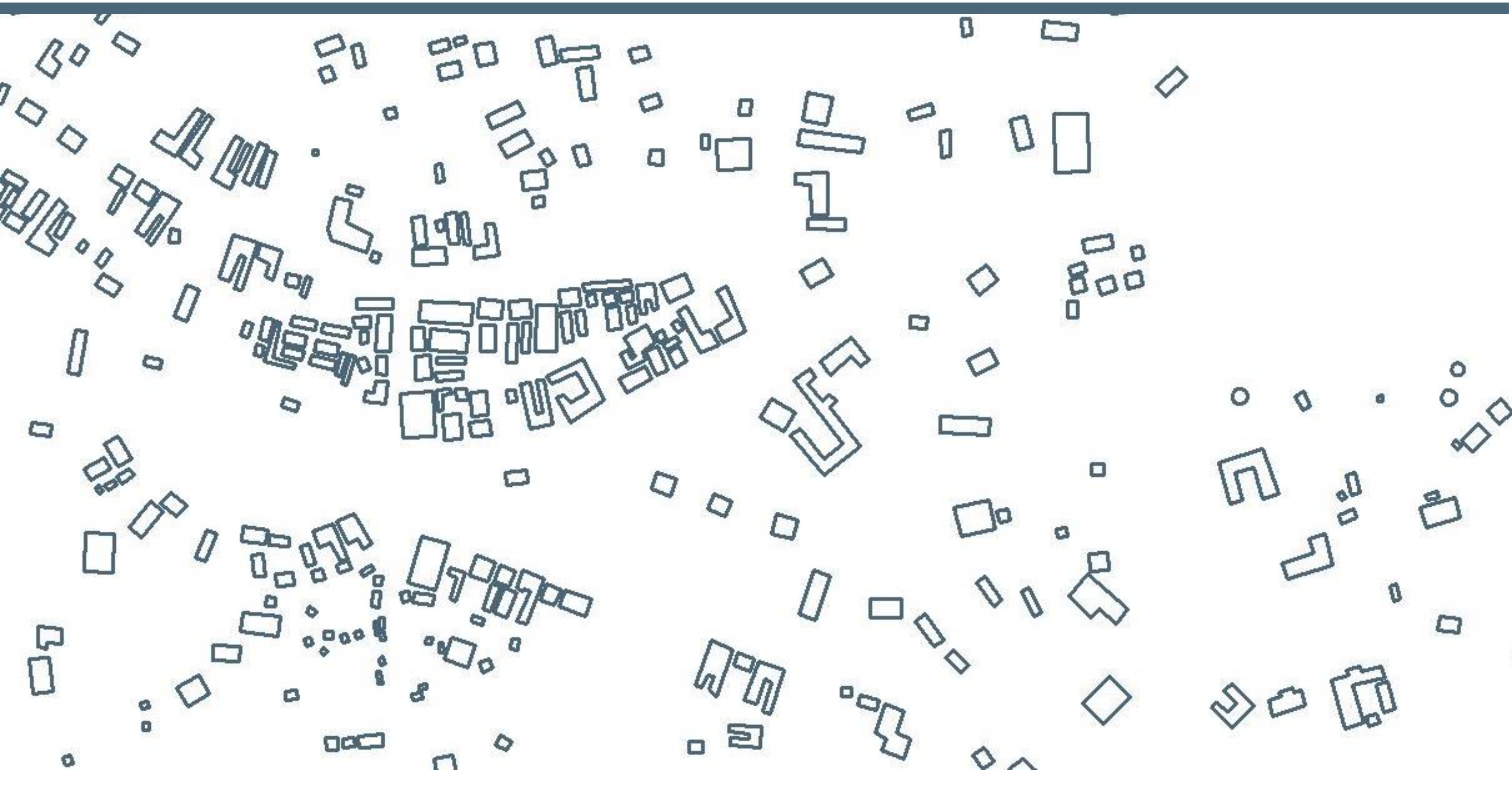
Access to Safe & Affordable Water in Moyo, Uganda through Rainwater Harvesting

Taylor M Bays | Spring 2022



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Abstract

A great portion of Moyo, Uganda's population lacks access to safe and reliable water, causing health issues, and even death. Efforts to improve Moyo's access to safe water have been implemented; however, achieving this goal in the last few years has slowed due to a lack of funding and proper maintenance. Research shows a need to decrease the distance between homes and their water sources. Rainwater harvesting could be a solution to this problem. However, Moyo lacks the spatial data required to calculate the rainwater harvesting potential. In this research, Moyo buildings were traced using satellite imagery, and the roof area was found for 1,590 buildings. Using the roof data combined with climate and demographic data, the minimum roof area needed to supply enough rainwater to meet a household's monthly demands were found. If Moyo receives an average amount of rainfall throughout the year, 86% of recorded buildings could meet the monthly demands after the first year of harvesting. There is potential for 1,407 buildings to have free, accessible water. Sanitation, hygiene, and the health of families could be improved if rainwater harvesting was practiced in Moyo.

1. Introduction

According to the World Health Organization (WHO), 2.2 billion people lack access to safely managed drinking water, causing 829,000 people to die each year from diarrhea.[1] WHO directly links these deaths to unsafe drinking water, poor sanitation, and hand hygiene.

Having access to safe and affordable water is a global issue. WHO states, "Globally, at least 2 billion people use a drinking water source contaminated with faeces".[2] As a result, 3.1 percent of documented deaths are due to unsafe drinking water.[3] Populations are suffering worldwide from consuming unclean water, lack of accessibility, or both. To make the problem even bigger, as a result of global warming, populations with current access to clean and safe water will suffer in the future from longer periods of heatwaves and droughts, which is why water conservation is essential.

Rural East Africa lacks access to clean and accessible water. For instance, 82% of households in Uganda do not have handwashing facilities, and 35% in rural areas do not have access to safe water.[4] In one of his books, Clarence Tsimpo discusses barriers to safe water and the major challenges of unsafe water. Sadly, unsafe water causes several health issues, including child morbidity, malnutrition, and mortality.[5]

In Moyo, Uganda, only 19.5% of households have access to piped water, while 64.7% of households use a borehole as their primary water source.[6] Issues arise when relying on a borehole as a primary source of water. Issues like lack of proper maintenance, shallow water levels, and it is time-consuming to retrieve the water.

[1] World Health Organization, (2019),"Drinking-water", accessed from https://www.who.int/news-room/fact-sheets/detail/drinking-water.
[2] World Health Organization, (2019).
[3] World Health Organization, (2002), "Year of healthy life can be increased 5-10 years, WHO says," accessed from https://www.who.int/news/item/30-10-2002-years-of-healthy-life-can-be-increased-5-10-years-who-says.

[4] Uganda Bureau of Statistics , (2021), "The Uganda National Household Survey 2019/2020": 160-170, https://www.ubos.org/wp-content/uploads/publications/09_2021Uganda-National-Survey-Report-2019-2020.pdf.
[5] Tsimpo, C, et al, (2018), "Challenges for Access to Safe Water: Qualitative Analysis," *Water and Sanitation in Uganda*: 39.
[6] Uganda Bureau of Statistics, (2017), "National Population and Housing Census: Moyo District 2014": 18.

Boreholes can easily become inoperable due to a lack of parts, repair costs that communities cannot afford, and difficulty finding well-trained technicians to maintain or fix the boreholes.[7] This forces households to travel even further distances to collect water, or it may leave them without access to water at all.

Collecting water from a borehole can be challenging to access, and only a limited amount of water can be taken back to the home for use. It takes time and energy to collect water. In Uganda, it takes an average of 47 minutes total.[8] Some days, multiple trips are made. Often, the women and girls of the household collect the water.[9] The time spent fetching water takes away from household duties like cooking, cleaning, and caring for the children. When women are forced to walk a long distance away from home, there is also more chance for crime to occur—it puts them in a risky situation.

To try and promote or assist access to safe water, the Ugandan Government introduced a National Development Plan II (2015-2020), which includes the following goal:

"Achieving access to safe water supply of 79% (rural) and 95% (urban) by 2020 and access to basic sanitation services of 80% by 2020".[10]

Since this plan was published, data was collected from communities. Between 2018-2020, the West Nile sub-region of Africa, including Moyo, reported that 39.9% of water sources had been improved, 32.2% remained unchanged, and 27.9% have deteriorated.[11] Challenges to achieving these goals include inadequate funding and resources. These challenges have slowed the progress of improving access to clean water and sanitation.

2. Research Questions

With the high percentages of households without handwashing facilities, unreliable boreholes, long and potentially dangerous trips to collect water, and the slow progress of improving safe water sources, this paper asks:

- **What is the minimum catchment area required to meet the water demands of an average household in Moyo, from January to December?**
- **How much rainwater could be captured for domestic use in the sub-county of Moyo?**

3. Literature Review

Water-related diseases account for a significant proportion of morbidity and mortality worldwide, including in Uganda. Tsimpo (2018) researched the challenges and constraints that prevent a household from benefitting from adequate sanitation in Uganda. Because human feces, animal feces, solid waste, and domestic wastewater are causing health problems for children and adults in Uganda, variables like sanitation levels were studied concerning the number and location of latrines and handwashing practices.

Tsimpo discovered that many households could not afford private latrines, and outside of households there are limited toilet facilities within the community. There are reports of improper waste removal and a lack of waste and sanitation regulations. The cost of handwashing and lack of knowledge about handwashing benefits prevent households from benefitting from adequate sanitation.

[7] Tsimpo, C and Wodon, Q, (2018), "Water and Sanitation in Uganda", International Bank for Reconstruction and Development / The World Bank, 44.
[8] "The Uganda National Household Survey 2019/2020," (2021): 163.
[9] Tsimpo and Wodon: 10.
[10] The Ministry of Health and Ministry of Water and Environment, (2017), "Uganda Overview: water, Sanitation and Hygiene".
[11] "The Uganda National Household Survey 2019/2020,": 165.

Handwashing practices and sanitation levels could be improved if families had access to clean water. Authors Onweng and Mulindwa (2019) studied strategies for improving access to safe drinking water sources for the poor in Uganda. They found that improved policies, increased resources, and continuous efforts to increase the number of protected water sources can help increase access to safe water. However, there is still work that needs to be done to ensure all have access to safe water.

In addition to improving policies and increasing resources, Onweng and Mulindwa realized a need to decrease the traveling distance between households and water sources.[12] As mentioned in the introduction, the household's women and girls often collect the water, ***Figure 1*.** Because collecting water takes time, household chores are delayed until they return home. After studying safe-water shortages and gender perspectives in Uganda, Baguma (2013) believes that if the time spent on household chores could be reduced, women could participate in or form local associations and improve the well-being of their community. Because household constraints are complex, Tsimpo informs his readers that community-specific solutions are important.[13]

Rainwater harvesting significantly shortens the distance between households and water. Baguma and Loiskandl (2010) investigated factors that most influence the adoption of tanks at the household level to ensure households have a water supply in rural Uganda. They conducted face-to-face interviews with Uganda household members over six months to determine what will make households more likely to practice rainwater harvesting. The study concludes that subsidy provision was statistically significant for adopting RWH technologies in rural Uganda. They suggest the consideration of household RWH subsidies in the form of hardware when promoting the adoption of RWH technologies versus cash offers. When subsidies in RWH construction materials are provided, having a RWH system installed seems more likely than when cash alone is provided.

As a result of "increasing water demands, water scarcity, and climate change variability," rainwater harvesting is a practice that would allow communities to have accessible and consistent water for both domestic and agricultural use.[14]

Figure 1: Woman pumping water from borehole (Nkhome, UM News)

The following section demonstrates how the rainfall and potential rainwater volumes can be measured for Moyo. After participating in literature reviews, it has been found that there is a lack of spatial data in Moyo, Uganda. The study aims to help solve this problem by providing data and quantitative results.

[12] Onweng, T. A., and Mulindwa, P., (2000), "The right to safe water: Situation analysis of women, adolescents and children in Uganda 1994-2000."
[13] Tsimpo, C, et al, (2018).

[14] Baguma, D., & Loiskandl, W, (2010), "Rainwater harvesting technologies and practices in rural Uganda: a case study", *Mitigation and adaptation strategies for global change*, 15(4).

3. Methodology

3.1. Study Area

The study site for the research conducted is located in Moyo, Uganda, the eastern region of Africa, ***Figure 2***. The Uganda Bureau of Statistics reported that the Moyo subcounty has a 2021 projected population of 12,100,[15] and the average household size in this region is 4.7 people.[16] In the district of Moyo, 88.9% of the population lives in a rural region.[17] Moyo has an average temperature of 81.6 degrees Fahrenheit, ***Figure 3***, and receives an average rainfall of 54.1 inches a year, ***Figure 4.*** Since only a fifth of the population has access to piped water, I mapped Moyo buildings and studied how much rainwater (in gallons) can be harvested for domestic use.[18]

3.2. Research Design and Conceptual Framework

The research design is quite simple and can be replicated for any town or city. The independent variables I used for this research are the square footage of non-thatched rooftops within the Moyo subcounty and the amount of rainfall Moyo receives per month. The dependent variable is how much rainwater can be harvested in Moyo each month, ***Table 1***. It is important to note that only non-thatched roofs were collected in the data and measurements. This is because the construction of a thatched roof will not support a RWH system. See ***Figure 5*** for the conceptual framework of the pilot study.

Figure 2: The subcounty of Moyo is displayed in red, this is the study site used for the collected data

[15] Uganda Bureau of Statistics, (2021), "Population and Census", accessed from https://www.ubos.org/explore-statistics/20/.
[16] Uganda Bureau of Statistics, (2017): 4.
[17] City Population, "Moyo", accessed on Oct 15, 2021, from https://www.citypopulation.de/en/uganda/admin/northern/029__moyo/.
[18] Water Supply Atlas, (2021), "Moyo District". Accessed from http://wsdb.mwe.go.ug/index.php/reports/district/25.

Figure 3: Data showing the monthly minimum, maximum, and average temperatures for Moyo from 2009 to 2021 (Climate Data)

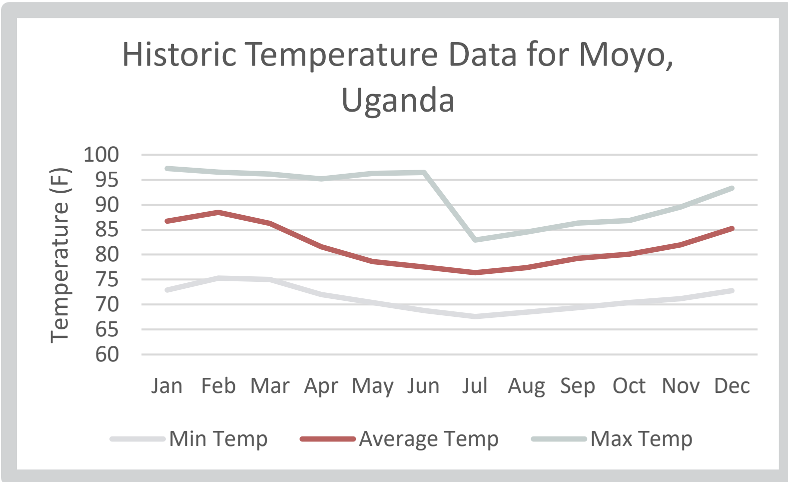


Figure 4: Data showing the monthly minimum, maximum, and average rainfall for Moyo from 2009 to 2021 (Climate Data)

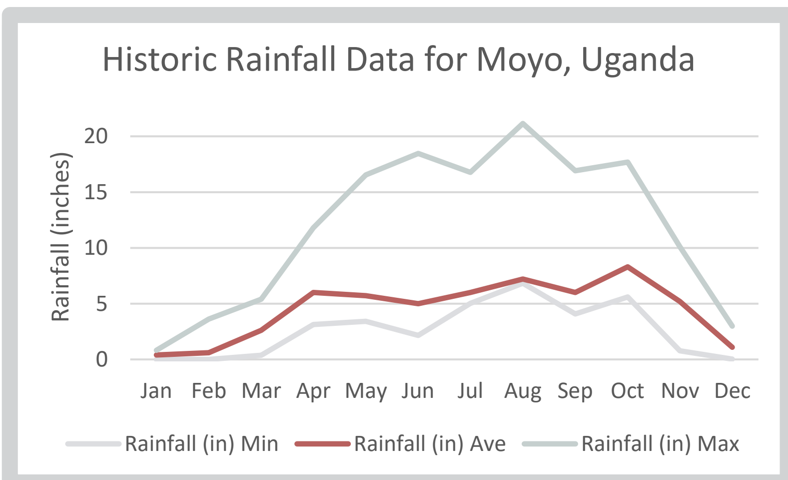
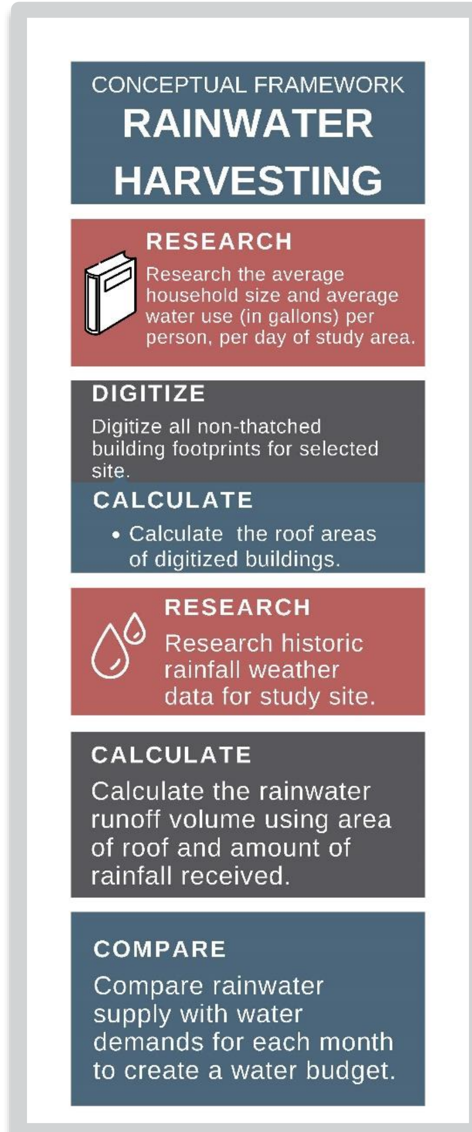


Figure 5: Conceptual framework of rainwater harvesting study



3.3. Data and Measures

The presented rooftop area data is new, primary data that I collected using computer software. The climate data is historic secondary data. The catchment area is the first component of a rainwater harvesting system as it determines how much rainwater can be collected. Rooftops are the easiest way to capture large quantities of rainwater. The amount of rain received is then used to determine how much rain can be collected by any rooftop area in a given period.

Table 1: Variables studied

Variable	Type	Description
Rooftop Area	Numeric	The catchment area in square feet
Rainfall	Numeric	The amount of rain received in inches
Runoff	Numeric	The volume of rain collected from rooftop area

3.4. Methods

The data for the research was collected using ArcGIS, an online geographic information system that includes imagery tools. The Moyo subcounty was first defined on a map. After that, the building footprints were digitized from satellite images, and the area of each rooftop was calculated. The calculated areas were used to determine the amount of rainwater runoff that can be harvested in relation to the precipitation data. See ***Appendix A*** as a representation of the 5-step process that was performed and the evidence that was documented.

Once I examined the results of my research, I used the information found to compare and contrast new Moyo data given to me by Pipeline Worldwide. In Section 5, I also applied these same methods to three case studies. These case studies belong to a Moyo project that the CAPLA 5th-year architecture studio is designing for Pipeline Worldwide.

4. Results

4.1 Research Results

The area was calculated for 1,590 non-thatched rooftops. This number includes both commercial and residential buildings, see ***Figure 6***.

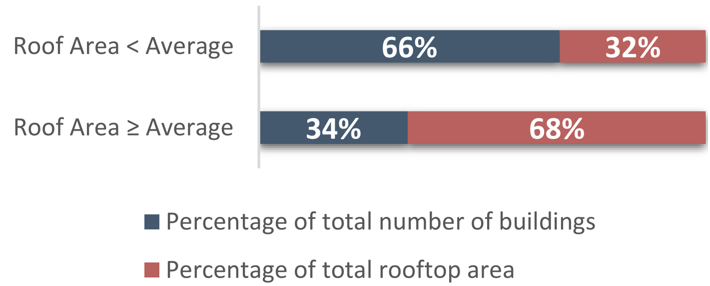
The area of the rooftops ranges from as little as 35 square feet (sf) to 21,965 sf. See ***Table 2*** for average and total-sizing. 66% of the buildings have a smaller rooftop than the average size, yet this only makes up 32% of the total square footage. In contrast, 34% have a rooftop size greater or equal to the average rooftop and makeup 68% of the total square footage, ***Figure 7.***

Figure 6: All non-thatched buildings in Moyo

Table 2: Data of rooftop areas in Moyo (sf)

Minimum	Maximum	Mean	Total of all Roofs
35	21,965	1,328	2,113,280

Figure 7: Comparison between the number of buildings and roof areas



The potential supply of rainwater that can be harvested was calculated using ***Equation 1.*** This equation includes the catchment area, the volume of rainfall, and the conversion number of 7.48, which converts cubic feet to gallons. It also includes a coefficient of 0.9, which is the maximum estimated runoff coefficient for metal roofs; 90% of rainfall will run off of a sheet metal roof.[19]

Equation 1 Net Runoff Calculation in gallons

$$\textbf{Net Runoff} = \textbf{Catchment Area}\ (ft^2)\ \text{x}\ \textbf{Rainfall}\ (ft)\ \text{x}\ 7.48\left(\frac{gal}{ft}\right)\ \text{x}\ \textbf{Runoff Coefficient}$$

According to the National Population and Housing Census of 2014, the average household size in Moyo is 4.7 persons.[20] Uganda's average water demand per person is 4.7 gallons of water per day.[21] The monthly demand for an average household was calculated by multiplying the number of days in the month by the household size and the gallons of water used per person, see ***Equation 2***. ***Table 3*** shows the monthly water demands of an average household.

Equation 2: Calculating the monthly water demand for an average Moyo household

$$\textbf{Monthly Water Demand} = \textbf{Gallons used per}\frac{day}{person}\ \text{x}\ \textbf{Household Size}\ \text{x}\ \textbf{Days in Month}$$

Table 3: Water demand for household size of 4.7 consuming 4.7 gallons of water per day

Month	Water demand (gal)
Jan	685
Feb	619
Mar	685
Apr	663
May	685
Jun	663
Jul	685
Aug	685
Sep	663
Oct	685
Nov	663
Dec	685
Yearly	8063

[19] Kinkade-Levario, H, (2007), "Design for Water", New Society Publishers: 83.
[20] Uganda Bureau of Statistics, (2017), "National Population and Housing Census: Moyo District 2014": 18.
[21] Golbert, K, (2020), "Uganda's Water Crisis and the Economy", *The Borgen Project,* accessed from https://borgenproject.org/ugandas-water-crisis-and-the-economy/.

A monthly balance can be found using the monthly water supply, determined by the amount of rainfall and roof area, and the monthly water demand. The balance is the roof runoff supply minus the water demand. The monthly balance is used to determine the cumulative available storage for each year of collection. Any surplus water at the end of the year can be used to meet the demands in the next year.

After organizing a water supply and demand table in Excel, Moyo roof areas were plugged in until each monthly demand was met by the demands of January through December in the first year is 3,395 sf. Out of all 1,590 buildings that have been documented, only 108, or 7%, have a large enough roof surface to ensure that each month meets the water demand of the average household size in the first year of collecting rainwater, ***Appendix B***.

Using the same method of calculations, the minimum roof requirement required to have surplus rainwater at the end of the first year that could carry over and meet all monthly demands of year two was found. Answering research question one, the minimum area is 311 sf, ***Appendix C***. After the first year of practicing rainwater harvesting, 88% of the Moyo buildings without a thatched roof could collect enough runoff to meet each month's demands of the average household, ***Figure 8***.

Using ***Equation 1***, wet and dry years can also be studied and predicted. Estimates can be made for various years using the weather data between 2009 and 2021. For example, ***Appendix D*** shows the water budget in an especially dry year with minimum roof requirements. The 311 sf roof will not be able to access rainwater on their property, forcing them to seek safe and clean water elsewhere.

Table 4 shows the monthly volume of rainwater that can be collected from all 1,590 buildings. The total amount of rainwater that Moyo could potentially harvest for one year is 64.2 million gallons, answering the second research question.

Figure 8: Percentage of Moyo rooftops with adequate area to collect enough rainwater at the end of year 1 to meet the monthly demands of year 2

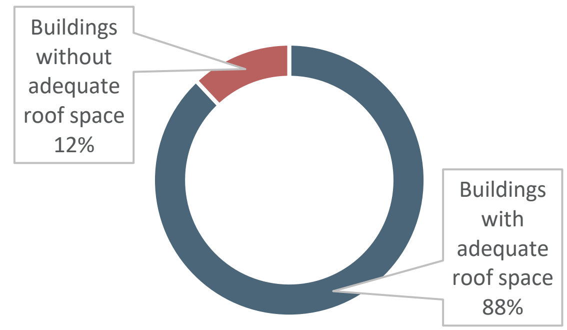


Table 4 Potential Runoff Volumes for Moyo

Month	Moyo rainfall (ft)	Rainfall collected from average size rooftop (gal)	Total amount of rainfall collected (gal)
Jan	0.03	268	4,436
Feb	0.05	447	7,396
Mar	0.22	1,967	32,531
Apr	0.50	4,470	73,934
May	0.48	4,290	70,977
Jun	0.42	3,755	62,105
Jul	0.50	4,470	73,934
Aug	0.60	5,364	88,721
Sep	0.50	4,470	73,934
Oct	0.69	6,169	102,029
Nov	0.43	3,844	63,583
Dec	0.09	805	13,308
Yearly	4.51	40,319	666,888

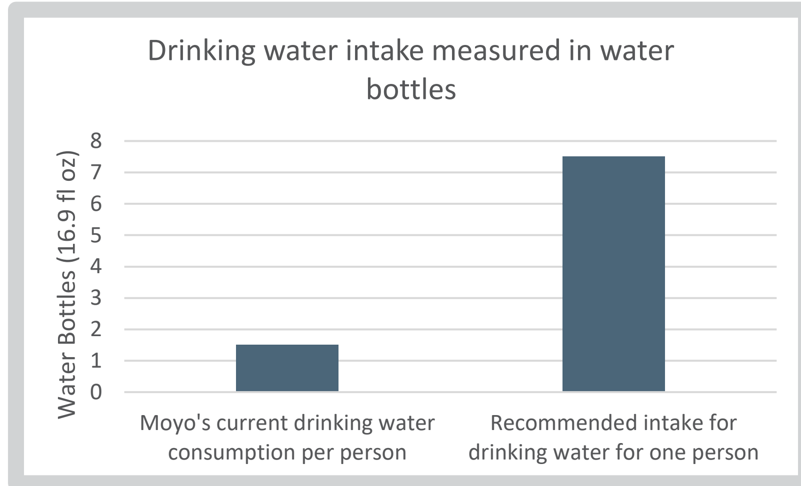
If the total population of Moyo is taken into consideration, the total water demand for one year is 33.4 million gallons**.** The total supply is greater than the total demand. However, if every rooftop documented was to harvest and store all rainwater, it would not be until year 2 that Moyo could meet each monthly water demand of its population.

Assuming Moyo receives the average amount of rainfall, almost 90% of the recorded buildings in Moyo have adequate roof space to harvest enough rainwater to meet the demands of an average household after the first year of rainwater harvesting. This result is that safe and affordable water can be accessible for many Moyo families. However, from the research, some families would be without any access to harvested rainwater. This can be due to the home's construction type; thatched roof construction is not adequate for RHW. Also, those without a large enough roof, or water storage, may not have 100% of their water demand met by rainwater in the first year of harvesting.

4.2 Comparing Data

Pipeline Worldwide presented new data later in the research process. Pipeline Worldwide is a company "delivering access to clean water, sanitation, education, and healthcare in the most impoverished regions." The company shared a recent water project site assessment conducted for a developing project in Moyo. A Moyo water engineer studied how villages around Moyo interacted with water. The study site included 224 households, and they found that the average people per household is six persons. The daily water consumption per person is 3.9 gallons. Of that amount, 0.16 gallons, or 4%, of their total water consumption is used for drinking. This amount is equal to 1.5 standard water bottles (16.9 fluid ounces). The U.S. National Academies of Sciences, Engineering, and Medicine recommend that humans intake an average of 0.8 gallons of water, or 7.3 water bottles, daily,[22] ***Figure 9***.

Figure 9: Comparing Moyo's current rate of drinking water intake per person to the recommended amount



Using the data received, if the current consumption rate of 3.9 gallons per day continued, the minimum roof area to supply a family of 6 is 329 sf. With average rainfall and enough storage, 329 sf will collect enough water at the end of year 1 to provide the family with a monthly surplus throughout year 2, ***Appendix E***. To meet the recommended amount of drinking water per person, the daily water consumption would have to increase by 0.8 gallons, matching the number found by Golbert, 2020. The minimum roof area that will collect enough water to sustain a family of six, consuming 4.7 gallons per day throughout year two of harvesting is 397 square feet, ***Appendix F***. 83% of the buildings digitized in Moyo have roof space to meet this demand. Surviving on rainwater in the driest year would

[22] Mayo Clinic, (2020), "Water: How much should you drink every day?", Accessed from https://www.mayoclinic.org/healthy-lifestyle/nutrition-and-healthy-eating/in-depth/water/art-20044256#:~:text=About%2015.5%20cups%20(3.7%20liters,fluids%20a%20day%20for%20women.

require an area of 974 sf is needed to meet the second year's demands, 46% of the recorded buildings.

Based on the results, rainwater harvesting could solve Moyo's water issues. As mentioned, roof materials and lack of funding for rainwater harvesting materials set limitations of how many families could participate in its practice. Without funding for cisterns, families can construct a small-scale system with gutters, buckets, and a mesh screen for filtration to meet some of their water needs.

5. Discussion + Application

Pipeline Worldwide has consented to the hazardous conditions of the water in Moyo. According to their water project site assessment, the water in Moyo is sourced by a nearby, unprotected stream. The reliability of the stream is poor. The volume varies per season, leaving the stream inadequate during dry seasons and fulfilled in the wet seasons. When the villages are blessed with a wet season, water quality is still poor. The stream is exposed to fecal and other contamination, causing health issues mentioned in the introduction. The water looks cloudy and has a foul odor to it. As a result, the community wished for new or alternative water supplies. Because many families lack access to municipal water and the inconsistencies related to boreholes, the potential for households to harvest rainwater in Moyo was studied.

If an average Moyo household desired to meet all monthly demands of the first year of rainwater harvesting, the minimum catchment area required is 4,329 sf. With average rainfall, this area will meet the water demands for a household of 6 persons that consumes 4.7 gallons daily from January to December. Out of the 1,590 buildings, less than 4% have the potential to collect enough water. However, the minimum area required to collect the amount of water needed to have a surplus at the end of the first year to fulfill the monthly demands of the second year is 311 sf. These numbers assume the current rate of water consumption will be stagnant. Observing Moyo as a whole, during an average year of rainfall, the 1,590 rooftops can collect 64.2 million gallons of water. The supply amount exceeds the population's water demand.

With the information found in this study, there was a chance to apply it to three smaller case studies. A CAPLA 5th-year architect studio has been working with Pipeline Worldwide on a developing campus for Pipeline Worldwide, visitors, and the Moyo community. The campus includes an office building, a pavilion with a kitchen and café, cottages, one residence, staff housing, a marketplace, and an ambulance kiosk. The potential of rainwater harvesting was observed for the office building, pavilion, and marketplace.

5.1. The Office

The office building includes three private offices for Pipeline's Africa Director, staff, and partners. There is a conference room for meetings with up to 20 attendees and two classrooms. One classroom is a computer lab, and the other is a healthcare training lab. Each classroom has space for 20 people. There will be two restrooms, and an outdoor garden. The entire building will have a roof space of 2,691 sf. With average rain, the building could potentially collect 81,702 gallons of water per year.

It has been assumed that there could be 17 employees in the offices, 20 attendees in the conference room, and 20 students in the classrooms. This building is expected to operate Monday to Friday, open from 8 am to 4 pm. Using LEED assumptions for fixture type and default uses per day, a mock water budget was created. The design conservation case includes low flush and flow rates. The water budget can be seen in ***Appendix G***. The only months that do not receive enough water to supply the building are January, February, and December, ***Figure 10***. Any excess stored water could be saved for a dry year or used for outdoor irrigation.

Figure 10: Yearly water supply and demand for the Office

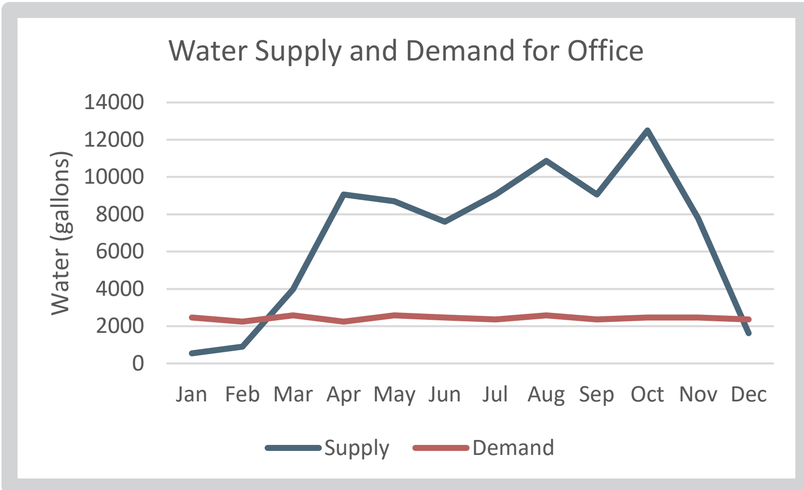
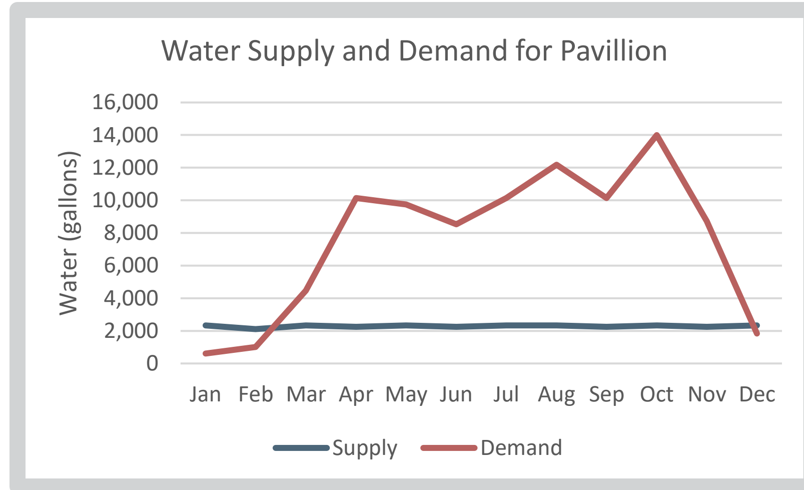


Figure 11 Yearly water supply and demand for the Pavilion



5.2. The Pavilion

The pavilion building includes a kitchen and a café. The total square footage is 3,014 sf. There are indoor and outdoor dining areas, with a kitchen outfitted to serve the residents and guests. The café will seat a maximum of 60 people, and a maximum of 8 employees will be working there. Two bathrooms will be included. Since this is a source of food and recreation for the campus, it is assumed that the pavilion operates 365 days a year. The total amount of rainwater needed is for the year is 29,168 gallons of water per year. The supply is larger than the demand for 75% of the year, ***Figure 11***. If there is the proper storage, the monthly demands of year two could be met, see ***Appendix H***.

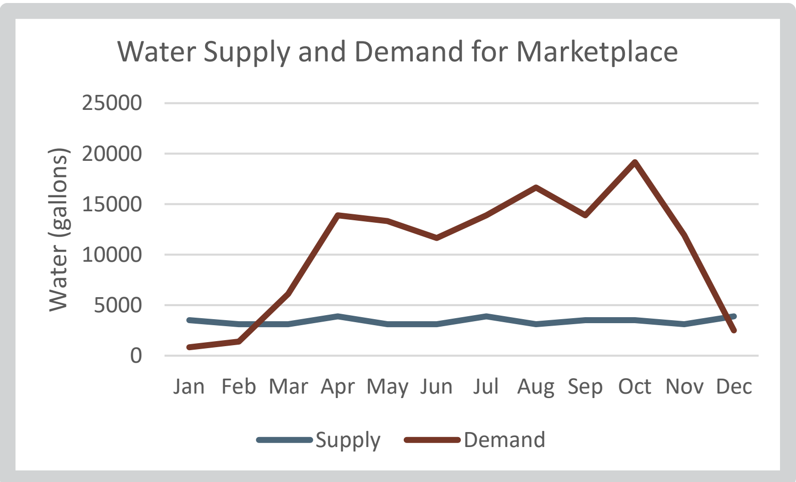
5.3. The Marketplace

The marketplace is an area of the campus that will be used mostly on the weekends as a farmers' market, a performance space, a food demonstration area, a global outreach center, a covered entry, two restrooms, and outdoor space for 10 venders. The roof areas for these spaces can be seen in ***Table 5.*** The marketplace can fit up to 562 visitors per day using this information. The annual water demand for the marketplace is 40,864 gallons, and with the roof coverings, 84,376 gallons of water could be harvested, see ***Figure 12*** and ***Appendix I***.

Table 5: Market Place Components

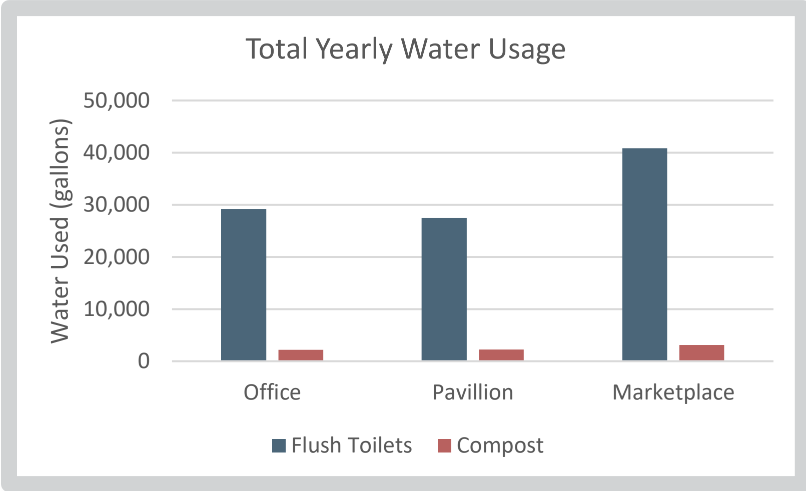
Structures	Area (sf)
Entry Way	750
Global Outreach	500
Food Demo	500
Performance Plaza	2,000
Restrooms	375

Figure 12: Yearly water supply and demand for the Marketplace



Pipeline Worldwide is installing flushable toilets on the campus that use rainwater or recycled greywater. If they decided to use composting toilets instead, 89,952 gallons of water would be saved a year. The differences for each building are shown in, ***Figure 13***.

Figure 13: The total water consumption with flushable fixture versus if compost toilets were installed



Reviewing the numbers collected and calculated based on the roof area and amount of rainfall, rainwater harvesting can increase water accessibility for Moyo families and commercial projects. Water conservation is essential when rainwater harvesting cannot supply enough water to meet the demands. Ideas such as low flush and low flow fixtures can reduce the amount of water needed. Toilets account for 83% of the yearly water demand in this mock water budget. A limitation to this part of the study was estimating occupancy and water demand.

There tends to be challenges when the architect of a project insists on certain components such as fixtures and materials. A challenge with the Moyo project has been relying on rainwater for toilet use versus composting toilets. With composting toilets, 83% of the water could be used elsewhere throughout the campus. Another challenge that arose was the roof materials. A metal roof is best to retain the highest amount of rainwater. However, a metal roof does not always fit the project's theme or look the best. The project in Moyo has discussed using bamboo and tiles. Tiles tend to work well for rainwater collection, but the runoff coefficient will be smaller than presented in this report.

In addition to these challenges, any rainwater used for drinking should be filtered and disinfected. Easy home methods include sand filtration and chlorine disinfection. Pipeline Worldwide wants to ensure that its drinking water is completely safe and potable. They have discussed using grey water for washing, flushing, and irrigation and municipal water for potable needs.

Aside from the challenges presented, rainwater harvesting can be a simple system. The minimum area requirements for different scenarios have been found, and the community of Moyo could benefit greatly from it. This research can help future communities discover if their location, climate, and roof type work well for rainwater collection.

Future research using rainwater harvesting includes finding methods to collect rainwater for those without a home. In Tucson, temperatures can rise to 120 degrees in the summer. People without homes suffer from dehydration and heat strokes. It would be interesting to dig deep and see if there are any ongoing projects for this. If so, I would like to help with the research, and if not, I would like to start collecting data and researching this dilemma. Rainwater harvesting can be beneficial to all communities.

6. Conclusion

There are 2.2 billion people on this planet consuming contaminated drinking water.[23] Unsafe conditions and lack of access to water result in several health issues and potentially death.

In Moyo, Uganda, 65% of households use boreholes as their main water source, and only 20% have access to piped water.[24] Research shows that boreholes can help communities access water, but many challenges arise. The travel distance between households and water sources needs to be reduced. The studies presented in this report were conducted to determine if Moyo has a rainwater supply that will meet their monthly water demands.

The research started by collecting rooftop data using satellite imagery of Moyo, Uganda. Each building was digitized in ArcGIS, and the roof area for 1,590 buildings was recorded. During this part of the research, a limitation was not physically being in Moyo. Climate and demographic data are required variables when constructing a water budget. The monthly water demand for an average family was determined using historical climate data and recent demographic data for Moyo. The climate data and the roof area are used to find the potential volume of roof runoff.

Comparing the water supply to the demand decides if the roof area is adequate for supporting the current lifestyle of the family. Once the monthly demands were found for average household size, roof areas were plugged into equations until there was enough rainwater for each month's neutral or positive balance.

If a family of 6 consuming 3.9 gallons of water per day is studied, 4% of Moyo buildings can collect enough water to meet the monthly demands in the first year of harvesting rainwater. Looking a year ahead, assuming there is average rainfall throughout the years, the minimum roof area needed is 329 sf. 83 percent of buildings already have the area to sustain families. If a family desired to meet the recommended daily water intake, they would need an additional 0.8 gallons, increasing the required roof size to 397 sf.

Moyo families could benefit from collecting rainwater and using it for domestic purposes. The family would have direct access to water, resulting in more time for household duties, family bonding, and education. Harvesting water has the potential to prevent health issues by providing safer water and allowing for improved sanitation

[23] World Health Organization, (2002).

[24] Uganda Bureau of Statistics, (2017).

practices. Direct access to free water is a sustainable solution to Moyo's water crisis in environmental and social pillars.

In addition to researching the domestic use of rainwater, a commercial project was investigated. Amongst the three case studies for Pipeline Worldwide, the Office, Pavilion, and Marketplace have the potential to harvest a supply of rainwater that could carry through year 2 of harvesting. Storing the volume of water needed could be difficult. Indoor water conservation could resolve this issue. If composting toilets were installed in the three buildings over flushable ones, 83% of the collected water would be conserved.

When rainwater harvesting is not an option, indoor water conservation methods should be examined. When indoor water conservations have been implemented, or simply cannot be used, rainwater harvesting can be an easy addition or a solution.

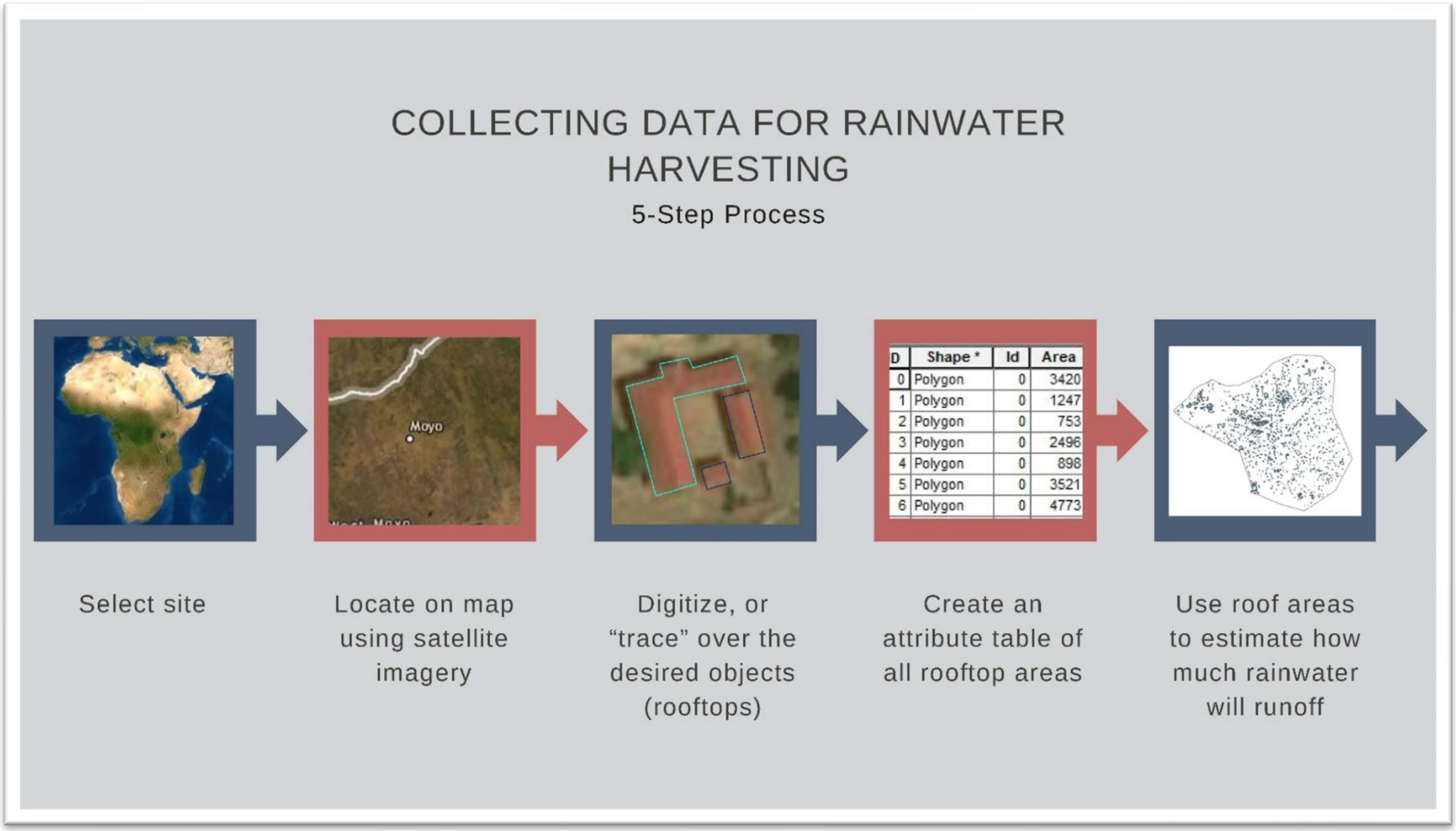
Collecting the proper rainwater harvesting materials is often a challenge. Baguma and Loiskandl (2010) found that when subsidies are given out to promote RWH, giving the necessary RWH materials versus cash is best. Moyo has the potential to supply their entire population with rainwater. Finding the method and materials to do so can be further investigated.

Rainwater harvesting can be practiced in any community. There has been an increase in water demands, causing water scarcity around the globe.[25] Using the methods and research discussed in this report, all communities can plan for proper RWH systems. Rainwater is free, accessible, and consistent, making it a sustainable way to obtain and use water.

[25] Baguma, D., & Loiskandl, W, (2010).

6. Appendix

Appendix A: 5-step process for collecting data



Appendix B: Budget for average household of 4.7, consuming 4.7 gallons of water per day, receiving average rainfall

Roof size 3,395 sf

Month	Rainfall (ft)	Supply (per month in gal)	Demand (per month in gal)	Balance (gal)	Cumulative available storage year 1 (gal)	Cumulative available storage year 2 (gal)
Jan	0.03	686	685	1	1	95,015
Feb	0.05	1,143	619	524	525	95,539
Mar	0.22	5,028	685	4,343	4,868	96,224
Apr	0.50	11,428	663	10,765	15,633	96,886
May	0.48	10,970	685	10,286	25,919	97,571
Jun	0.42	9,599	663	8,936	34,855	98,234
Jul	0.50	11,428	685	10,743	45,598	98,919
Aug	0.60	13,713	685	13,028	58,627	99,603
Sep	0.50	11,428	663	10,765	69,391	100,266
Oct	0.69	15,770	685	15,085	84,477	100,951
Nov	0.43	9,828	663	9,165	93,642	101,614
Dec	0.09	2,057	685	1,372	95,014	102,298
Total	**4.51**	**103,077**	**8,063**	**95,014**		

Appendix C: Budget for average household of 4.7, consuming 4.7 gallons of water per day, receiving average rainfall

Roof size 311 sf

Month	Rainfall (ft)	Supply (per month in gal)	Demand (per month in gal)	Balance (gal)	Cumulative available storage year 1 (gal)	Cumulative available storage year 2 (gal)
Jan	0.03	63	685	-622	-622	758
Feb	0.05	105	619	-514	-1,136	244
Mar	0.22	461	685	-224	-1,360	20
Apr	0.50	1,047	663	384	-976	404
May	0.48	1,005	685	320	-656	724
Jun	0.42	879	663	217	-439	940
Jul	0.50	1,047	685	362	-77	1,302
Aug	0.60	1,256	685	571	494	1,874
Sep	0.50	1,047	663	384	878	2,258
Oct	0.69	1,445	685	760	1,638	3,018
Nov	0.43	900	663	238	1,876	3,255
Dec	0.09	188	685	-496	1,380	2,759
Total	**4.51**	**9,442**	**8,063**	**1,380**		

Appendix D: Budget for average household of 4.7, consuming 4.7 gallons of water per day, receiving minimum rainfall

Roof size 311 sf

Month	Rainfall (ft)	Supply (per month in gal)	Demand (per month in gal)	Balance (gal)	Cumulative available storage year 1 (gal)	Cumulative available storage year 2 (gal)
Jan	0.00	0	685	-685	-685	-3,269
Feb	0.00	0	619	-619	-1,303	-3,888
Mar	0.03	65	685	-620	-1,924	-4,508
Apr	0.26	544	663	-118	-2,042	-4,626
May	0.29	597	685	-88	-2,130	-4,714
Jun	0.18	375	663	-288	-2,418	-5,002
Jul	0.42	876	685	191	-2,227	-4,811
Aug	0.57	1,192	685	507	-1,720	-4,304
Sep	0.34	712	663	49	-1,671	-4,255
Oct	0.47	977	685	292	-1,378	-3,963
Nov	0.07	136	663	-527	-1,905	-4,489
Dec	0.00	5	685	-680	-2,584	-5,169
Total	**4.51**	**5,478**	**8,063**	**-2,584**		

Appendix E: Budget for average household of 6, consuming 3.9 gallons of water per day, receiving average rainfall

Roof size 329 sf

Month	Rainfall (ft)	Supply (per month in gal)	Demand (per month in gal)	Balance (gal)	Cumulative available storage year 1 (gal)	Cumulative available storage year 2 (gal)
Jan	0.03	66	725	-659	-659	789
Feb	0.05	111	655	-544	-1,203	244
Mar	0.22	487	725	-238	-1,442	6
Apr	0.5	1,107	702	405	-1,036	412
May	0.48	1,063	725	338	-698	749
Jun	0.42	930	702	228	-470	978
Jul	0.5	1,107	725	382	-88	1,360
Aug	0.6	1,329	725	603	515	1,963
Sep	0.5	1,107	702	405	921	2,369
Oct	0.69	1,528	725	803	1,724	3,171
Nov	0.43	952	702	250	1,974	3,422
Dec	0.09	199	725	-526	1,448	2,896
Total	**4.51**	**9,989**	**8,541**	**1,448**		

Appendix F: Budget for average household of 6, consuming 4.7 gallons of water per day, receiving average rainfall

Roof size 397

Month	Rainfall (ft)	Supply (per month in gal)	Demand (per month in gal)	Balance (gal)	Cumulative available storage year 1 (gal)	Cumulative available storage year 2 (gal)
Jan	0.03	80	874	-794	-794	966
Feb	0.05	134	790	-656	-1,450	310
Mar	0.22	588	874	-286	-1,736	24
Apr	0.5	1,336	846	490	-1,246	515
May	0.48	1,283	874	409	-837	923
Jun	0.42	1,122	846	276	-561	1,200
Jul	0.5	1,336	874	462	-99	1,662
Aug	0.6	1,604	874	729	631	2,391
Sep	0.5	1,336	846	490	1,121	2,881
Oct	0.69	1,844	874	970	2,091	3,851
Nov	0.43	1,149	846	303	2,394	4,155
Dec	0.09	241	874	-634	1,760	3,521
Total	**4.51**	**12,053**	**10,293**	**1,760**		

Appendix G: Water budget for the Office

Building: Office/Classroom	Employees	Visitors	Total
Occupants	17	60	77
Toilet Use	51	30	81
Public lavatory faucet use	51	30	81

Table: Project Information						
Month	Occupants	Water Usage (gal)	Water Supply (gal)	Balance (gal)	Cumulative Storage Year 1	Cumulative Storage Year 2
Jan	1,694	2,468	543	-1,925	-1,925	50,610
Feb	1,540	2,244	906	-1,338	-3,263	49,272
Mar	1,771	2,580	3,985	1,405	-1,857	50,677
Apr	1,540	2,244	9,058	6,814	4,957	57,491
May	1,771	2,580	8,696	6,115	11,072	63,606
Jun	1,694	2,468	7,609	5,141	16,213	68,747
Jul	1,617	2,356	9,058	6,702	22,915	75,449
Aug	1,771	2,580	10,869	8,289	31,204	83,738
Sep	1,617	2,356	9,058	6,702	37,906	90,440
Oct	1,694	2,468	12,500	10,032	47,938	100,472
Nov	1,694	2,468	7,790	5,322	53,260	105,794
Dec	1,617	2,356	1,630	-725	52,534	105,068
Total		29,168	81,702	52,534		

Annual Days of Operation	261 working days

Table: Flush Fixtures				
Fixture Type	Flush Rate (gpf)	Duration (sec)	Total Daily Uses	Total Daily Water Use (gal)
Toilet	1.28	n/a	81	103.68

Table: Flow Fixtures				
Fixture Type	Flow Rate (gpm)	Duration (sec)	Total Daily Uses	Total Daily Water Use (gal)
Public lavatory faucet	0.21	30	81	8.51

Table: Total Flush and Flow Water Use	
Total Daily Water Use (gal)	112.19

Appendix H: Water budget for the Pavilion

Building: Pavilion	Employees	Visitors	Total daily uses
Occupancy	8	60	68
Toilet Use	24	30	54
Public lavatory faucet use	24	30	54
Kitchen faucet use	8	0	8

Table: Project Information						
Month	Occupants	Water Usage (gal)	Water Supply (gal)	Balance (gal)	Cumulative Storage Year 1	Cumulative Storage Year 2
Jan	2,108	2,332	609	-1,723	-1,723	62,335
Feb	1,904	2,106	1,015	-1,091	-2,814	61,243
Mar	2,108	2,332	4,464	2,132	-682	63,376
Apr	2,040	2,256	10,145	7,889	7,207	71,264
May	2,108	2,332	9,739	7,408	14,615	78,672
Jun	2,040	2,256	8,522	6,266	20,880	84,938
Jul	2,108	2,332	10,145	7,814	28,694	92,751
Aug	2,108	2,332	12,174	9,843	38,537	102,594
Sep	2,040	2,256	10,145	7,889	46,425	110,483
Oct	2,108	2,332	14,000	11,669	58,094	122,152
Nov	2,040	2,256	8,725	6,469	64,563	128,620
Dec	2,108	2,332	1,826	-505	64,057	128,115
Total		27,452	91,509	64,057		

Annual Days of Operation	365 working days

Table: Flush Fixtures				
Fixture Type	Flush Rate (gpf)	Duration (sec)	Total Daily Uses	Total Daily Water Use (gal)
Toilet	1.28	n/a	54	69.12

Table: Flow Fixtures				
Fixture Type	Flow Rate (gpm)	Duration (sec)	Total Daily Uses	Total Daily Water Use (gal)
Public lavatory faucet	0.21	30	54	5.67
Kitchen faucet	0.21	15	0	0.42

Table: Total Flush and Flow Water Use	
Total Daily Water Use (gal)	75.21

Appendix H: Water budget for the Marketplace

Building: Market Place	Visitors	Total daily uses
Marketplace	562	562
Toilet use	281	281
Public lavatory faucet use	281	281

Table: Project Information						
Month	Occupants	Water Usage (gal)	Water Supply (gal)	Balance (gal)	Cumulative Storage Year 1	Cumulative Storage Year 2
Jan	5,058	3,503	833	-2670	-2,670	81,707
Feb	4,496	3,113	1388	-1725	-4,395	79,982
Mar	4,496	3,113	6109	2996	-1,399	82,978
Apr	5,620	3,892	13885	9993	8,594	92,971
May	4,496	3,113	13329	10216	18,810	103,187
Jun	4,496	3,113	11663	8550	27,360	111,737
Jul	5,620	3,892	13885	9993	37,353	121,730
Aug	4,496	3,113	16662	13549	50,902	135,279
Sep	5,058	3,503	13885	10382	61,284	145,661
Oct	5,058	3,503	19161	15658	76,942	161,319
Nov	4,496	3,113	11941	8828	85,770	170,147
Dec	5,620	3,892	2499	-1393	84,377	168,754
Total		40,864	125,240	84,376		

Annual Days of Operation	105 working days

Table: Flush Fixtures				
Fixture Type	Flush Rate (gpf)	Duration (sec)	Total Daily Uses	Total Daily Water Use (gal)
Toilet	1.28	n/a	281	359.68

Table: Flow Fixtures				
Fixture Type	Flow Rate (gpm)	Duration (sec)	Total Daily Uses	Total Daily Water Use (gal)
Public lavatory faucet	0.21	30	281	29.51

Table: Total Flush and Flow Water Use	
Total Daily Water Use (gal)	389.19

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