Rainwater Harvesting and Automated Off-grid Irrigation for Food and Water Security in Guatemala

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***Abstract*—Research was conducted at the Barbara Ford Peace Building Center in Santa Cruz del Quiché, Guatemala regarding the effects of climate change on food and water security. A rainwater harvesting system and an off-grid automated irrigation system were designed and analyzed as methods of decreasing water scarcity and labor intensity in the agricultural sector. The rainwater harvesting system was constructed at the Barbara Ford Peace Center and used to collect local rainwater capture data over several weeks. Cost analysis of the system was performed and its yields at a rural home nearby were projected. A cost analysis was also performed on the automated irrigation system. Off-grid power sources were also appropriately sized and recommended for the system. Lastly, the client was also given specific crop recommendations for cultivation in Quiché.**

***Index Terms*—agriculture and food security, water conservation, rainwater harvesting, agricultural technology, sustainability, irrigation and farming practices, off-grid system design**

I. Introduction

Climate change is contributing to inconsistent rainfall and extreme droughts, threatening water security across the globe. By 2040, it is estimated that one in four children will reside in places with extremely high water stress [1]. Climate change intensifies the effects of droughts by increasing their severities, frequencies, and durations. Consequently, terrestrial water storage has dropped at a rate one centimeter per year for the past two decades [2].

The consequences of recently dwindling water supplies is felt strongly in the Central American Dry Corridor (CADC), which covers 44% of the surface of Guatemala, Honduras, El Salvador, and Nicaragua [3]. Over half of residents of the CADC region work in agriculture, primarily subsistence cultivation of basic grains [3]. Unfortunately, 80% of these farmers live in poverty, and the new scarcity of usable water has been destructive to their livelihoods [4]. In 2019, 2.2 million people in the CADC experienced extreme crop losses following four consecutive years of drought [5]. Water insecurity combined with high poverty levels and few opportunities for advancement leave them with little options. The result is massive emigration rates, primarily of young people. Emigration from the CADC increased by 500% between 2010 and 2015, and almost a third of the migrants reported extreme weather as the main cause of their departure [5].

At 293%, Guatemala has the second-highest increase in emigration rate between 1990 and 2020 out of the Central American Dry Corridor [6]. About half of the total population and nearly 80% of the indigenous population (who comprise over 40% of the total population) live in poverty [7]. It is no surprise that these groups also experience high rates of food insecurity: almost half of children under five years old are malnourished [8].

A vast majority of Guatemalan migrants travel to Mexico and ultimately to the United States. Huehuetenango, Quiché, and San Marcos are the Guatemalan departments with the highest number of apprehensions of people arriving at the United States Southern Border as family units between 2012 and 2019 [9]. These departments compose three out of four of the highest rural populated departments by percentage: the percentages of rural population in Huehuetenango, Quiché, and San Marcos are 72%, 68%, and 75% respectively [9]. Agricultural stress linked to climate change appears to be a major factor responsible for the departure of Guatemalan migrants. An increase of a department's Food and Agriculture Organization Annual Agricultural Stress Index from 0% to 9% of cropland affected corresponds to an 84% increase in apprehensions from that department the following year [9] [10]. Climate change induced agricultural stress is only expected to increase in coming years. By 2050, Guatemala's primary crops, maize and beans, are predicted to have their yields decreased by 14% because of climate change. Sugarcane yields are predicted to drop by 35% in the same period [11].

Bolstering agricultural resilience to climate change comes out as the best method to protect the endangered livelihoods of rural Guatemalans. Specifically, low-cost solutions to water insecurity and irrigation in times of drought will have a profound effect. Rainwater harvesting systems appear to be a promising endeavor with great potential. Another important consideration as temperatures rise is the necessity to cultivate crops like coffee at higher altitudes [11]. Agriculture is already the most labor intensive sector of the Guatemalan economy, and watering steep mountainside fields at high elevations will be strenuous. Automating irrigation in an efficient manner, such as a passive drip irrigation system, can provide significant decreases in the labor associated with mountainside farming. Together, rainwater harvesting systems and automatic irrigation systems can provide a strong advantage to Guatemalans battling water and food insecurity.

Fig. 1. Mountainside corn field in Guatemala [12]

II. Background

A. The Barbara Ford Peace Center

The Barbara Ford Peace Center is a non-profit humanitarian organization founded by the Sisters of Charity of New York in 2009. Located in the rural highlands of Santa Cruz del Quiché, it aims to promote the integral human development of vulnerable people (primarily indigenous people and women) in Guatemala. The Barbara Ford Center hosts various outreach and educational programs focussed on citizenship, public health, and economic advancement. Recognizing the vital role of agriculture in the local economy, the Barbara Ford Center has undertaken multiple initiatives to boost this sector. For example, el Proyecto Más Riego (the More Irrigation Project) is a collaboration with various organizations and universities, including the USAID Horticulture Innovation Lab, University of California at Davis, Kansas State University, and the Zamorano Pan American Agricola School, to promote better agricultural practices. The Barbara Ford Center has initiated the Centro de Investigación y Promoción del Campesinado (CIPCA) project to launch various educational programs related to raising livestock and cultivation of nutritious crops [13].

Every year, the Barbara Ford Center collaborates with The Cooper Union for the Advancement of Science and Art, a private undergraduate university in New York City, for the Summer Study Abroad program [14]. This program enables engineering students to spend six weeks researching and developing solutions to real-world problems at the Barbara Ford Center. In the past, Cooper students have worked on projects addressing electricity access and water conservation.

A.S. worked with the Barbara Ford Center to develop his rainwater collection and automatic irrigation system through the Summer Study Abroad program. After discussion with the Barbara Ford Staff and locals in the nearby city of Chiché, it was decided that this project would be the most relevant area for A.S. to help the local Guatemalans. A prototype of the system was designed and evaluated at the Barbara Ford Center in order to assess its performance and predict its viability at the Chiché location.

B. Geographical Characteristics of Guatemala

Santa Cruz del Quiché is a city in the Western highlands of Guatemala. Located on Sierra de Chuacús mountain range at an elevation of 2,021 meters above sea level, Santa Cruz del Quiché features jagged and mountainous terrain [15]. Santa Cruz also falls in the tropical zone, so it remains warm all year [16]. The average temperature of each month ranged from 13.4 degrees Celsius to 16.6 degrees Celsius in 2019 [17]. Instead of experiencing four solar seasons, Santa Cruz del Quiché experiences a wet season and a dry season, marked by large disparities in precipitation. On average, Quiché experiences the lowest level of precipitation in February and the highest level of precipitation in June: 53.13 millimeters and 377.85 millimeters respectively [18].

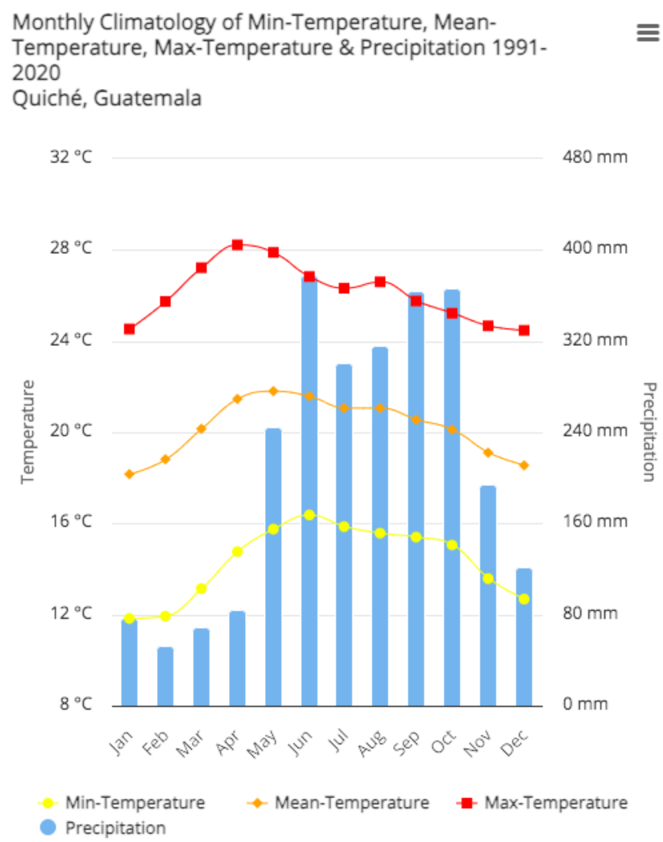

Fig. 2. Quiché, Guatemala Climate History [18]

C. Modelo de Producción Rural

The Modelo de Producción Rural (MPR) is a small building at the Barbara Ford Peace Center. It was designed as a model for a basic house of a local Guatemalan farmer. It is 6.6 meters wide and 5.8 meters long, covering a total area of 38.28 m^2. The corrugated-steel rooftop perimeter is 24.8 meters, which is relevant because it affects the length of PVC pipe required for the rainwater harvesting system installation. The MPR will

Fig. 3. The Modelo de Producción Rural

serve as the implementation and evaluation site for both the rainwater harvesting and automatic irrigation systems.

Fig. 4. MPR sky view

D. Chiché Location

The Chiché location is an off-site house owned by a local Guatemalan family of five people. It covers a total area of 148.22 m^2. The Chiché house also has a corrugated rooftop and the perimeter is 56.91 meters. There is 43.53 m^2 of available garden space in front of the house and 83.52 m^2 behind it. The Chiché location will serve as the reference point of a rural family plot in Quiché. The viability and performance of the rain harvesting and automatic irrigation system will be estimated at this location based on its functionality at the MPR.

III. Methodology

A. Rainwater Harvesting System

A basic rainwater harvesting system is installed at the MPR and the water level of the tank is recorded over a period of 35 days to confirm the applicability of online data used for further calculations. The catchment surface is the corrugated-steel A-frame roof. The rain gutters are PVC pipes with a lengthwise incision that wrap around the edge of the roof. The downspout is also made of PVC pipe. Lastly, the storage

Fig. 5. Chiché Location

Fig. 6. Chiché Location sky view

Fig. 7. Rainwater Harvesting System Installed at MPR

tank is cylindrical plastic with a capacity of 2500 liters. All of these materials were purchased from Soluciones Hidráulicas y Eléctricas de Occidente (S.H.E.O.) in Santa Cruz del Quiché.

TABLE I
COST OF RAIN WATER HARVESTING SYSTEM AT MPR

Item	Quantity	Cost (Quetzales)	Cost (USD)
2 inch PVC	20 Meters	334	42.47
PVC Cap	2	20	2.54
PVC Elbow	3	75	9.54
PVC Tee	1	25	3.28
Tank	1	3000	381.49
TOTAL	—	3454	439.32

B. *Off-grid Automated Irrigation System*

The goal of the off-grid automated irrigation system is to decrease the labor associated with watering fields on steep mountainous terrain. Additionally, the system is designed to conserve water through precise dosing. Both of these purposes serve to adapt Guatemala's agricultural sector as water grows scarce and rising temperatures drive farms to higher elevations.

Fortunately, mountainous terrain lends itself well to a gravity-fed irrigation system, which conserves significant energy. The liquid solenoid valve, a valve controlled by electric current, is central to the operation of the off-grid automated irrigation system. When placed at the outlet port of the tank, the solenoid valve permits water to flow downhill to a drip irrigation system at specified time intervals. However, a control circuit is required to achieve this effect. In this case, the Adafruit KB2040 microcontroller was used — primarily because it was the microcontroller with the lowest power consumption on-site. The solenoid valve requires nine volts and 0.27 amps and the KB2040 can only supply a maximum three volts and 0.5 amps, so the valve is driven by a relay. A capacitive soil moisture sensor was also added so the valve is only activated when the soil is sufficiently dry. This prevents redundant over-watering and conserves water. Furthermore, a water level switch placed in the tank will be connected ahead of the relay to prevent the valve from engaging without an adequate amount of water present, thereby saving power. Lastly, the system will most likely be situated in areas where electricity is not available, so a battery is required to power it. Solar is the best option to charge the battery to avoid high costs of operation over time. The power consumption of the system will be investigated and a battery and solar panel will be sized in this report.

The KB2040 is programmed using the circuit python code seen in Figure 10. The code is optimized to decrease the power consumption of the circuit. For example, the capacitive soil moisture sensor is only powered on for 0.1 seconds per day to read the soil moisture level. The valve is only activated if this moisture level is adequately low, preventing the waste of power on unnecessary watering. On top of this, the KB2040 enters a daily deep sleep of about 23.5 hours depending on the crop. In this case, the irrigation time is 30 minutes per day.

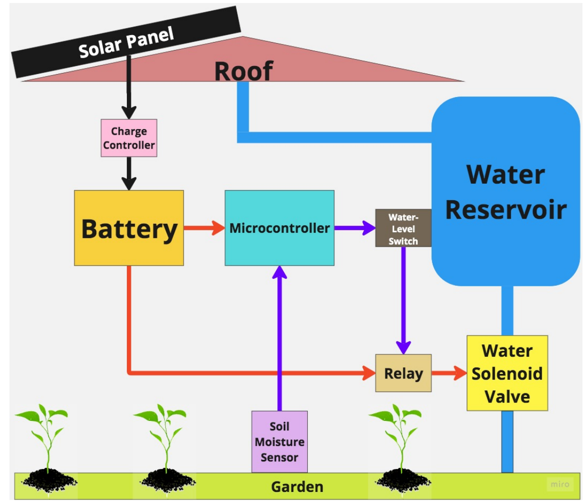

Fig. 8. Off-grid irrigation system diagram

TABLE II
COST OF OFF-GRID AUTOMATED IRRIGATION SYSTEM

Item	Cost (USD)	Source
Adafruit KB2040	8.95	Adafruit
Brass Liquid Solenoid Valve	50.87	S.H.E.O.
L7805CV Voltage Regulator	0.68	Digikey
Tactile Push Button	0.45	Digikey
1 Kilo Ohm Resistor	0.10	Digikey
2N2222 NPN Bipolar Junction Transistor	0.24	Digikey
1N4007 Diode	0.11	Digikey
5 Volt Relay	1.31	Digikey
Water Level Switch	5.33	Amazon
Capacitive Soil Moisture Sensor	2.40	Amazon
Breadboard	3.34	Amazon
TOTAL	73.78	—

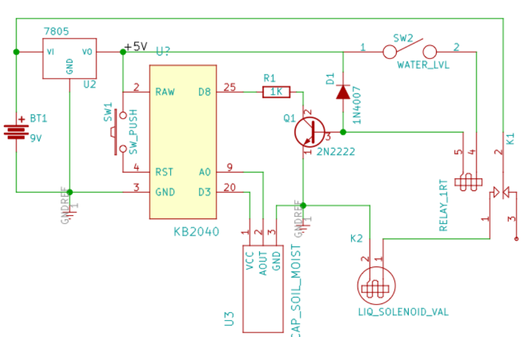

Fig. 9. Circuit schematic of the off-grid automated irrigation system control unit

See Table X for the the required irrigation time for different crops monocultures at the Chiché location.

```
import alarm
import time
import board
import analogio
import digitalio

# Initialize pins

analog_pin = analogio.AnalogIn(board.A0)

valve = digitalio.DigitalInOut(board.D8)
valve.direction = digitalio.Direction.OUTPUT

smPwr = digitalio.DigitalInOut(board.D3)
smPwr.direction = digitalio.Direction.OUTPUT

# Apply power to soil moisture sensor and take reading

smPwr.value = True
time.sleep(0.05)
n = analog_pin.value
time.sleep(0.05)
smPwr.value = False

# Activate valve for 30 min if soil is dry

if n < 35000:
        valve.value = True
        time.sleep(1800)
        valve.value = False

# Deep sleep for the remainder of the day

time_alarm = alarm.time.TimeAlarm(monotonic_time=time.monotonic() + 84600)

# Sleep and reboot

alarm.exit_and_deep_sleep_until_alarms(time_alarm)
```

Fig. 10. KB2040 Circuit Python code for off-grid automated irrigation system control unit

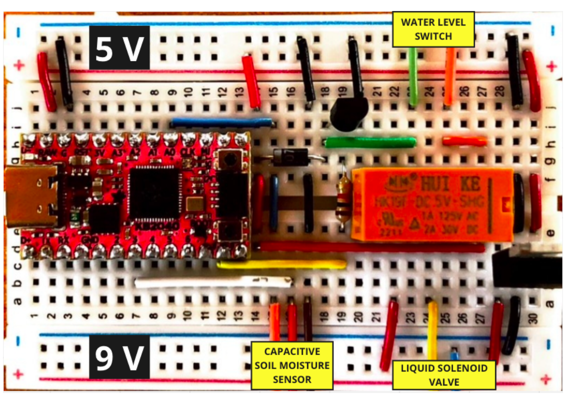

Fig. 11. Breadboard prototype of circuit schematic in figure 9

The valve releases one liter of water in 8.2 seconds, establishing a flow rate of 7.32 liters per minute.

IV. Results and Discussion

A. Rainwater Harvesting System

Figure 11 contains the rain water collection data at the MPR for 35 days between July and August. The cumulative volume water collected was 9.6 m^3 over this period. An average of 274 liters of water was collected at the MPR per day, so an average of 7.2 liters of water was captured per square meter of roof per day.

TABLE III
Off-grid Automated Irrigation System Power Consumption

State	Current (A)	Voltage (V)	Power (W)
Valve Closed (KB2040 is in deep sleep)	0.01	8.54	0.085
Valve Open (KB2040 is active)	0.28	7.70	2.16

Fig. 12. Off-grid automated irrigation system connected drip irrigation system at MPR

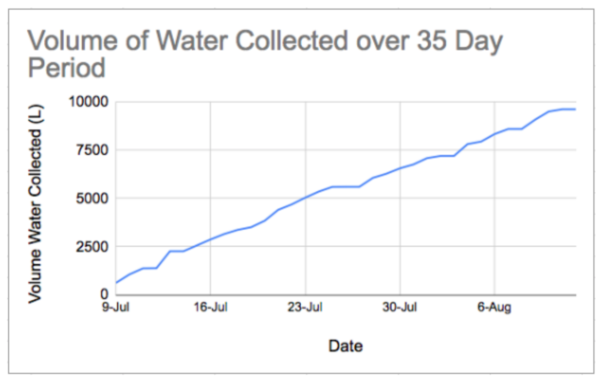

Fig. 13. Graph of cumulative water collected at the MPR over 35 days

B. Confirming the Applicability of Online Data

According to the data from the World Bank Climate Change Knowledge Portal shown in Figure 2, the average cumulative precipitation 1991-2020 over the period of the experiment is 308.85 mm. Assuming 100% water retention, the MPR would collect 11.82 m^3. Applying the runoff coefficient of 0.82 derived from previous research [19], yields the final theoretical cumulative volume of 9.69 m^3 of water, which agrees with the experimental data. Additionally, the increased experimental precipitation rates seen in August are also reflected in the online data. The experimental data confirms the data in Figure 2 is applicable for further calculations.

C. Potential System Yields

Based on Figure 2, the average precipitation during the wet season in Quiché is 1970.86 mm and the average precipitation during the dry season is 598.92 mm, for an annual total of 2569.78 mm from 1991-2020. Given the MPR's rooftop area of 38.28 m^2, it is expected to capture 98370 liters of water in one year: 75440 liters in wet season and 22930 liters in the dry season. The goal of the system is to store the water accumulated during wet season for use during dry season. A water reservoir with a volume of 75.44 m^3 will be necessary. For reference, a cylindrical tank with diameter and height of 5.8 meters will be required to achieve this capacity. Similarly, the Chiché location is expected to harvest 380890 liters of water over its 148.22 m^2 rooftop in one year. 292120 liters will be captured in the wet season and 88770 liters will be captured in the dry season. To store the water collected in wet season, a 292.12 m^3 vessel is necessary. A cylindrical tank with height and diameter of 7.2 meters will meet this requirement. These calculations are summarized in Table IV.

TABLE IV
EXPECTED RAINWATER YIELD AT EACH LOCATION

	MPR	Chiché Location
Dry Season Water Capture (L)	22930	88770
Wet Season Water Capture (L)	75440	292120
Annual Water Capture (L)	98370	380890
Required Tank Capacity (m^3)	75.44	292.12
Diameter and Height of Cylindrical Tank (m)	5.8	7.2

Such tanks are both unrealistic and uneconomical. Moreover, the height of the tank cannot exceed the height of the roof in a gravity-fed system. Another restriction to tank size is the area of the base because it will consume valuable garden space in more crowded areas. Underground or pond-style tanks may circumvent this issue, but they are more expensive to install and are unsuitable for gravity fed systems.

The Chiché location has a height of 1.87 meters and 43.53 m^2 of viable garden space in front. The additional garden space behind the house is uphill, rendering it impractical for the implementation of a passive irrigation system. Given these parameters, installing three tanks identical to the 2500 L tank at the MPR will be suitable. The total capacity will be 7500 L, and they will occupy a rectangular area of 6.93 m^3. Fortunately, these tanks will adequately fit on the side of the house (see Figure 6) so they will not consume space from the front garden.

TABLE V
COST APPRAISAL OF RAIN WATER HARVESTING AT CHICHÉ LOCATION

Item	Quantity	Cost (Quetzales)
2 inch PVC	41 Meters	684
PVC Cap	2	20
PVC Elbow	3	75
PVC Tee	1	25
2500 L Reservoir	3	9000
TOTAL	—	9804

D. Rain Harvesting System Break-Even Points

The cost of irrigation at the Barbara Ford Peace Center — which is primarily the electricity cost of pumping the water from a well at the bottom of the property — is 6.86 Q/m^3 [19]. Unfortunately, the Chiché Location does not have access to running water. For the sake of the break-even point calculations, the same price of pumping water is assumed. While break-even points are not necessarily relevant for homes without any running water, it may serve as a valuable criterion to compare rain harvesting systems implemented at different scales.

For both systems, the cost of the initial investment was plotted against the electricity cost savings each year to determine the break even points. Equations (1) and (3) are the investment costs of at the MPR and Chiché locations, while (2) and (4) are the respective annual savings.

$$f_1(x) = 3454(1.04)^x \tag{1}$$

$$g_1(x) = 674.82x \tag{2}$$

$$f_2(x) = 9804(1.04)^x \tag{3}$$

$$g_2(x) = 2612.91x \tag{4}$$

TABLE VI
BREAK EVEN POINTS OF RAINWATER HARVESTING SYSTEMS

RHS	Initial Investment (Q)	Annual Savings (Q)	Break Even Point (Years)
MPR	3454	674.82	6.64
Chiché Location	9804	2612.91	4.47

E. Crops

The Barbara Ford Peace Center seeks to uplift the living standard of Guatemalans. Recognizing the prevalence of malnutrition among vulnerable communities, the cultivation of nutrient-dense crops was requested as a design consideration. The following crops were selected for their high nutrient densities and low water footprints: soybean, spinach, lettuce, cauliflower, and broad beans [20]. Table VII contains the yield limiting factors of each crop [21] [22].

TABLE VII
YIELD LIMITING FACTORS

Crop	Maturity Period (Days)	Yield (kg/m^2)	Water footprint (m^3/ton)
Soybean	100	0.28	2107
Spinach	42	1.5	132
Lettuce	53	3	161
Cauliflower	1.85	674.82	211
Broad Beans	0.35	674.82	1521

Table VIII contains the maximum theoretical annual yield of each crop at the MPR and the Chiché location based on water footprint alone. The MPR currently does not have any available garden space. The maximum possible yield subject to

TABLE VIII
MAXIMUM THEORETICAL ANNUAL YIELD SUBJECT ONLY TO WATER CONSTRAINT

Crop	MPR Yield (kg)	Chiché Location Yield (kg)
Soybean	46.687	180.774
Spinach	745.227	2885.580
Lettuce	610.994	2365.776
Cauliflower	466.209	1805.166
Broad Beans	64.675	250.421

TABLE IX
MAXIMUM THEORETICAL ANNUAL YIELD SUBJECT TO BOTH WATER AND SPACE LIMITATIONS

Crop	Yield per Harvest (kg)	Number of Harvests Possible	Max Annual Yield (kg)
Soybean	12.190	3	36.565
Spinach	65.295	8	522.360
Lettuce	130.590	6	783.540
Cauliflower	80.531	2	161.061
Broad Beans	15.236	4	60.942

space and water limitations of each crop at the Chiché location is listed in Table IX.

For all crops, the limiting factor was garden space. Cultivating multiple harvests of the crop in the same year may overcome the space limitation. Vertical farming methods are also effective in limited space, but they are not always compatible with gravity-fed irrigation systems due to their height. Even when maximum yield for each crop is achieved, there is at least 254 m^3 of water remaining. This water is adequate to cover all other household needs, including bathing or washing dishes and clothes.

F. Grey Water

Greywater refers to household wastewater that is not contaminated with feces or urine. Sources of greywater include sinks, showers, and appliances. This water is often still usable for irrigation and may be added to the storage tank after minimal treatment.

G. Health Concerns

1) Contamination: Biological debris, such as leaves and bird feces, may enter the tank and contaminate the water. Likewise, the corrugated steel roof may corrode, especially under UV exposure, and introduce contaminants. Both of these sources of contamination pose serious health concerns if the tank water is ingested [23]. Health concerns can be mitigated if filters are added to the design and the water is not ingested by humans.

2) Mosquitoes: Female mosquitoes lay eggs in bodies of standing water. They may use the tank of the rainwater harvesting system for this purpose. This poses a health concern because it can increase the spread of mosquito-borne illnesses, including malaria, dengue, and zika [24]. Covering and sealing the tank will mitigate this issue. Mosquitoes are less populous at higher elevations [25].

H. Off-grid Automated Irrigation System Power Calculations

The power consumption of the automated irrigation system will depend on the water requirement of the garden, which varies based on size and crop. Table X lists the daily power consumption associated with irrigating the garden at the Chiché location for each crop.

TABLE X
DAILY POWER CONSUMPTION OF IRRIGATION SYSTEM BASED ON CROP

Crop	Water per Harvest (m^3)	Water per Day (L)	Daily Irrigation Time (min)	Daily Power Consumption (Wh)
Soybean	25.68	256.81	35.1	3.25
Spinach	8.62	205.21	28.0	3.01
Lettuce	21.02	396.70	54.2	3.91
Cauliflower	98.79	2	13.5	2.51
Broad Beans	257.48	4	35.2	3.26

TABLE XI
BATTERY SIZE DEPENDING ON CROP

Crop	Battery Required for 3 days of Operation
Soybean	9 V, 1.08 Ah
Spinach	9 V, 1.00 Ah
Lettuce	9 V, 1.30 Ah
Cauliflower	9 V, 0.84 Ah
Broad Beans	9 V, 1.09 Ah

Two 9V, 600 mAh batteries connected in parallel to provide a total of 1.2 Ah should be sufficient to power the system for most crops. These batteries will cost 10 USD (5 USD each) [26]. A 20 W solar panel will produce 120 Wh given 6 hours of sunlight a day, which is more than enough. This solar panel will cost 38 USD [27]. Lastly, a charge controller is required to safely recharge the battery. The Adafruit bq24074 solar lithium battery charger will cost 14.95 USD [28]. After adding these elements, the final price of the off-grid automated irrigation system becomes 136.73 USD or 1075.35 Q. Fortunately, cheaper alternatives are available for the most expensive component: the liquid solenoid valve. Replacing the brass valve with plastic dramatically reduces the price of the system. Adafruit offers a solenoid valve that only costs 6.95 USD [29], which would decrease the total price of the system to 92.81 USD or 729.93 Q.

V. CONCLUSION AND RECOMMENDATIONS

The performance of a rainwater harvesting system and an off-grid automated irrigation system were investigated in Quiché, Guatemala in order to determine their potential to alleviate water insecurity and boost agricultural resilience to climate change. The prototype rain harvesting system located at the MPR proved to be very effective; it was projected to capture 75440 liters during the Guatemalan wet season. The rainwater retention data from the MPR was extrapolated and supplemented with longitudinal online data to predict the performance of a similar rainwater collection system at a rural home in Chiché, Guatemala. At this location, rainwater harvesting demonstrated massive potential as well. The water storage tank emerged as the primary obstacle to the widespread implementation of rain harvesting systems. Large tanks required to store all of the water are very expensive and are not viable in restricted space. The use of multiple smaller tanks is proposed as a good trade-off between storage capacity and money or space restrictions. All together, the Chiché location is optimal for the application of a rain harvesting system. It is expected to capture 292120 liters of water during the wet season.

Specific crops —including soy, spinach, lettuce, cauliflower, and broad beans— were selected due to their high nutrient density to water footprint ratios. However, the yields at the Chiché location were primarily restricted by space, not water. Thus, the Chiché location will also sustain nutritious crops with higher footprints, such as onions. Farmers may overcome space limitations by growing multiple harvests a year. Every year, two harvests of spinach are recommended due to its high maximum yield and nutrient concentration, and one harvest of soy is recommended due its nutrient profile and nitrogen fixing ability [30]. Enabling Guatemalan farmers to grow more nutritious crops will ultimately mitigate the prevalent malnutrition.

The off-grid automated irrigation system was investigated to decrease the labor intensity of agriculture on the mountainous terrain frequently seen in the largely indigenous Western Guatemalan highlands. The automated irrigation system is not recommended for the Chiché location. The cost of the system is not justified for the corresponding decrease in labor. The garden at the Chiché Location is only 43.53 m^2 and it is comparatively level. The off-grid automated irrigation system designed in this project is better suited for application in both larger and steeper fields where labor is more intense (See Figure 1).

Both of the above systems may be implemented in areas around the world facing similar circumstances, such as other nations in the Central American Dry Corridor. Future work may include implementing these systems in other locations and tracking their performances over extended periods of time. Fortunately, the Barbara Ford Peace Center currently plans to begin implementation of the rain harvesting system at the Chiché Location and numerous other homes in Chiché and Totonicapan, Quiché before the wet season in 2024. Solutions to decrease the cost of larger tanks and additional research into filtering systems will greatly increase the investment value and performance of rainwater harvesting. The automated irrigation system will most benefit from further research to decrease the power consumption.

As the effects of climate change continue to increase in magnitude, new techniques may be necessary to adapt. Widespread adoption of rainwater harvesting and the off-grid automated irrigation systems serve to decrease the rising labor and water requirements of the Guatemalan agricultural sector. Additionally, new and innovative techniques should specifically uplift predominantly indigenous rural populations. Alleviating agricultural stress should decrease the large efflux of young Guatemalan emigrants.

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