Rainwater Energy Harvesting In Leyte, Philippines for Micro-Hydropower Use

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Abstract*—Leyte is a province in the Philippines that has an abundant amount of rainfall with mean annual rainfall of 2589.72 mm. The regular occurrence of typhoons in the province of Leyte has brought a huge amount of rainfall to the province. However, the rainwater becomes waste flowing down the drains causing flood, especially in urban areas. LGUs has not yet introduced a framework to harvest the huge amount of rainwater and utilize its equivalent stored potential energy. With this, the study introduces rainwater harvesting system that incorporates the utilization of energy stored in the rainwater harvesting system. The study calculates the equal amount of energy produced using rainwater. The rainwater energy harvesting includes the following: the floor area and roof area of residential buildings in Leyte province as catchment facility, the rainfall precipitation from two (2) PAGASA weather stations, and the number of rainy days in the Leyte province. The study employed theoretical power and energy equations in computing the equivalent stored potential energy by utilizing the average rainfall amount in the province with the average floor area specified from the approved building permits as of first quarter of 2022 with an initial building height of 5 meters.

***Indexed Terms*—Energy, Rainwater, Micro-hydro power, Harvesting, Rain Harvesting**

I. INTRODUCTION

In a tropical country like Philippines, abundant rainfall is considered a water resource for development. However, it is not fully used due to the seasonality of its occurrence [1]. Leyte, a province in the Philippines, welcomed the heavy rainfall because it provides and supplies the necessary water for agricultural purposes and even for domestic use. The presence of rainfall exists in many locations and is considered an abundant source of water. On the other hand, heavy rainfall also caused deadly and destructive flash floods. The use of this water resource was investigated in terms of rainwater harvesting systems, also known as RWH or RHS, even if it can have a detrimental influence in certain regions. [2].

The lack of irrigation and washing water sources, as well as drinking water, has been linked to studies on rainwater collection. Harvesting rainwater is an ancient practice that is regarded as a renewable energy source. This suggests that this RWH contributes to sustainable development because it has no negative environmental effects when compared to conventional energy [3].

Early research on RWH hasn't considered the potential for energy production from using rainwater that has been stored. In these studies, rainwater is collected in the tanks purposely to be sprayed on the roof for cooling purposes. Other studies utilized the collected rainwater for washing purposes or as a supply on non-potable water. If rainwater is collected, the utilization of it for any purpose could be a source of energy. This is accomplished by gathering and storing the rainwater at a specific building height or at the same height as the current structure. When rainwater is stored, a small-scale hydro-turbine, such as an overshot water wheel or any hydro turbine for slow water flow, can be used to generate energy from the gravity flow of water [4]. This small-scale generated energy could light up appliances in homes and buildings.

In this study, by employing theoretical power and energy calculations, the idea of harvesting the rainwater's equivalent energy is taken into consideration. The amount of rainfall in millimeters, the size of the building's roof or floor, its height, and the amount of water used all had an impact on this rainwater energy equivalent.

1.1 Classification of hydropower

The Philippines has vast hydropower potential, due to the heavy rainfall precipitation throughout the country, with more than 14.7% share from the total power generation mix of 2021. The Department of Energy (DOE) defines the hydropower plants in the Philippines based on their capacity. Large hydropower plants have generation capacity of more than 10MW. Mini-hydropower plants are termed for power plants with a generation capacity of 101KW to 10MW. Micro-hydropower plants are those with generation capacities between 1 and 100 kW[5].

1.2 Energy Harvesting from Rainwater for residential/building systems

RHW in residential and building provide energy by extracting power from high head water pipes through water catchment from rooftops for individual buildings located in regions where typhoons or heavy rains are common [6]. Water heads of 2 meters can be suitable to generate power efficiently with proper implementation of advanced technology[7]. Though in comparison to other forms of energy generation this is minimal, the energy harnessed of RWH can generate micro-hydropower and provide low-cost solutions as an alternative energy source.

II. MATERIALS AND METHODS

2.1. Runoff Coefficient

Runoff coefficient (Cr) is a factor affecting rainwater collection depending on the type of roofing used in structures[2]. Several studies assumed the runoff coefficient to be 0.80 for each day over the ten-year period. Another study assumed Cr to be 0.75. Although the term "runoff coefficient" is frequently used in the literature, it is incorrect because the quantity of rain that is retained depends on the overall amount of each precipitation event [9]. In this study, a Cr of 1.0 was considered.

2.2. Climatological Normals in Leyte Province

There were 2 site locations in the Leyte province in which the monthly amount of rainfall was observed. The rainfall precipitation considered in this study was a 30-year rainfall data from 1991-2020 [10]. The average amount of rainfall in this rainfall data was considered as basis in computing the energy equivalent of RWH in Leyte province. The number of rainy days is also used in this study as a determinant on what month heavy rainfall usually occurs.

2.3. Catchment Area

The floor area and roof area of different types of approved buildings in the Philippines as of the first quarter of year 2022 is the catchment area that determines the equivalent energy of rainwater harvesting [11]. Data were from the website of Philippine Statistic Authority (PSA). Dwelling units and residential buildings were categorized as shown in Table I below.

Table I. Roof Area and Floor Area of Residential buildings in Leyte province

Dwelling Unit		Residential Building [11]	
Type	Roof Area (m^2)	Type	Floor Area (m^2)
1	50	Single	137.91
2	75	Duplex/Quadruplex	86.00
3	100	Apartment	355.14
4	150	Condominium	-
5	200	Other Residential	-

Factors in assessing rainwater harvesting and utilization were the roof area or floor area of the building as well as the runoff coefficient, Cr [2]. The average floor area in the Leyte province, has the average floor area of 137.91 m² for single dwelling unit, 86.0 m² for duplex/qoud, and 355.14 m² for an apartment. Floor area of non-residential building were 315.14 m² for commercial, 419.77 m² for institutional, and 120 m² for agricultural buildings [11].

2.4. Computation of Equivalent Energy of Rainwater

The average amount of rainfall on two sites were considered in computing the potential rainwater energy equivalent. By using equations (1) and (2) below, the equivalent potential energy of rainwater collected from the buildings was computed [2] as,

$$PE = \delta g V_{ol} H C_r \qquad (1)$$

$$V_{ol}=R_pR_a \quad (2)$$

Where PE is potential energy in Joules, V_{ol} is volume of water in m^3, g is gravity in 9.8 m/s^2, δ is water density equal to 1000 kg/m^3, H is water head in meter (m), and $C_r$is the runoff coefficient equal to 1. R_p is the rainfall amount in mm and R_a is the building roof area or floor area in m^2. Conversion of Joules to watt-hour is express by 1 watt-hour = 3600 Joules (J). Similarly, 1 watt is equivalent to 1 Joule per second.

2.5. Household appliances power rating

The power rating of common household appliances was considered in computing the running hours or duration of these appliances based on the potential power output of the rainwater. Data were from the website of Visayan Electric Company (VECO) [12]. Table 2 below shows the common household appliances and their corresponding power requirements.

Table II. Power rating of common appliances

Fixture/Equipment	Wattage
Stand Fan 16”	74
DVD/VCD Player	300
TV Set Color, 20”	110
Fluorescent Lamp	25
Rice Cooker, 1-liter	450
Water Dispenser	550
Refrigerator, 8-cu. Ft.	150
Personal Computer	225
Laptop	60

2.6. Water Consumption Per Person Per Day

Depending on the kind and use of the water, different volumes of water are assumed. The shower, washing machine, dishwashing, toilet flushing, outside washing, kitchen taps, and basin taps are examples of water use. Water consumption for domestic use in a dwelling unit is tabulated shown in Table 3 below [4]. In any type of residential building, the amount of water consumed by each occupant (p) each day (d) is specified in liters (L)[9].

Table III. Dwelling Units water consumption

Dwelling Unit locations	Volume of water consumed per person per day (L/p/d)
Shower	60
Toilet flushing	45
Washing machine	12
Kitchen ta	12
Basin tap	21
Kitchen tap	12
Dishwashing	2
Outside washing	2

III. RESULTS AND DISCUSSION

3.1. Amount of Rainfall in the Leyte province

There were 2 weather stations of Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) in the Leyte province in which monthly rainfall amount was observed [10]. Rainfall precipitation for the past 30 years (1991-2020) was converted into a graphical interpretation to determine the rainfall amount. Figure 1 shows the amount of rainfall (in mm) of Tacloban City and Maasin City. The average rainfall amount of Tacloban City was 236.72 mm while Maasin City averaged 194.9 mm. The average rainfall of these two stations, which is 215.81 mm, was used to compute the energy equivalent of rainwater. Figure 1 and 2 below shows the rainfall precipitation of the 2 stations per month and the number of rainy days in a month. The highest average rainfall precipitation of Tacloban City was recorded in December with a precipitation value of 450.4 mm. In Maasin City, the highest average rainfall precipitation was recorded during the month of January with a rainfall amount of 289.2 mm.

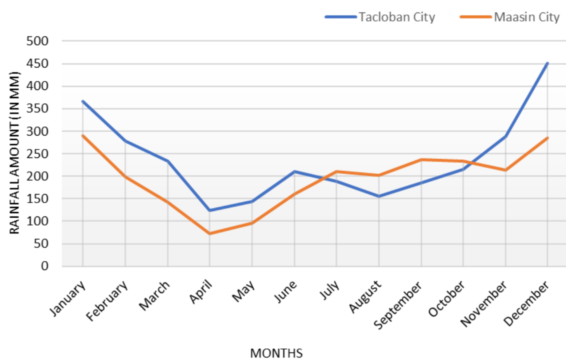

Figure 1. Rainfall precipitation of Tacloban and Maasin City

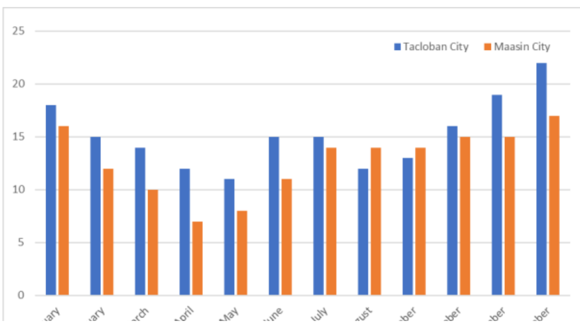

Figure 2. Number of Rainy Days in Tacloban and Maasin City

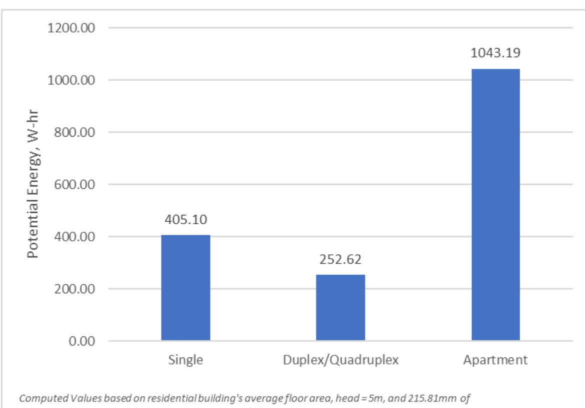

Figure 3. Equivalent rainwater potential energy for different types of residential buildings

Both weather stations recorded their lowest rainfall precipitations during the month of April amounting to 124 mm and 71.9 mm, for Tacloban City and Maasin City, respectively.

3.2. Potential Energy of Rainwater from Residential Buildings

There are four (4) types of residential buildings: single dwelling unit, double/quodro, apartment, condo, and other residential. Figure 3 and 4 below shows the potential energy of rainwater for each type of residential and non-residential buildings in the Leyte province. The computation assumed a height of five (5) meters applied to all types of building. The potential energy equivalent is computed only for the first 5-meter height of the building using the average rainfall precipitation from Tacloban and Maasin City stations. As shown in Figure 3, the first 5-meter height of the building has the highest equivalent energy of 1043.19 W-hr for apartment type of residential building and1233.04 W-hr for institutional buildings of non-residential units as shown in Figure 4.

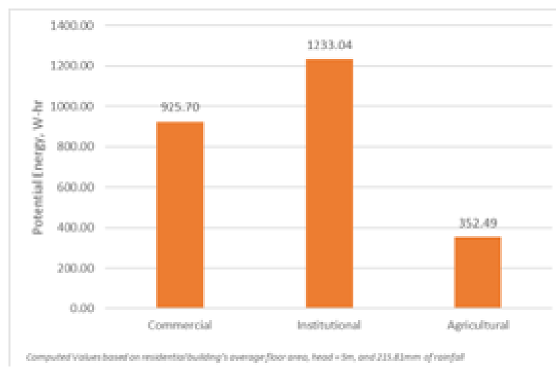

Figure 4. Equivalent rainwater potential energy for different types of non-residential buildings

3.3. Duration of common household appliances using rainwater energy

The energy harvested from the rainwater can be used to power common household appliances. The equivalent potential energy from rainwater of a single-unit dwelling can light a single fluorescent lamp up to 16.2 hrs. The harvested rainwater energy can also last an hour when a rice cooker of 450 watts is used. On non-residential buildings such as agricultural buildings, the harvested rainwater energy can light up a single fluorescent lamp for 14 hours or it can power twenty-five 25-watts fluorescent lamps simultaneously. Figure 5 and 6 below shows the hour-duration of common household appliances as they consume the energy harvested from rainwater in a single-unitresidential building and a non-residential agricultural building while Table 4 tabulates the different hour-duration of common household appliances when using the harvested potential rainwater energy from residential and non-residential buildings.

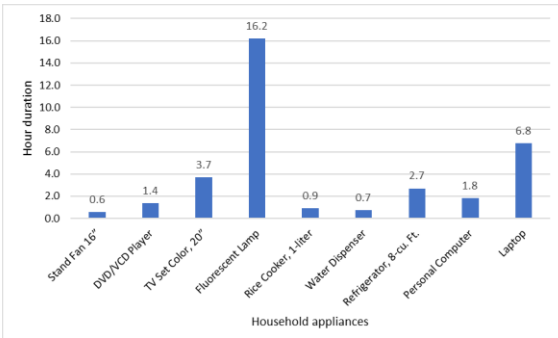

Figure 5. Duration of common appliances using rainwater energy from a single-unit dwelling

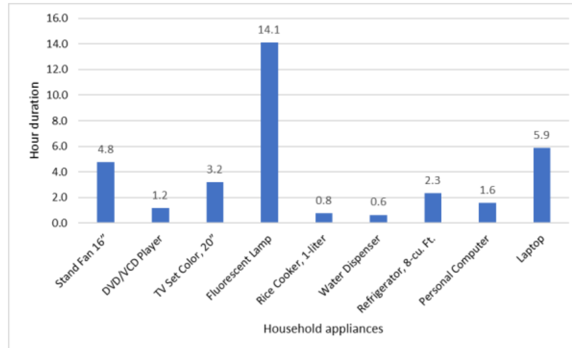

Figure 6. Duration of common appliances using rainwater energy from agricultural building

Table IV. Hour-duration of appliances using the rainwater energy from different types of building

Appliances	Residential buildings			Non-residential buildings		
	Single	Duplex	Apartment	Commercial	Institutional	Agricultural
Stand Fan 16”	0.6	0.3	1.4	12.5	16.7	4.8
DVD/VCD Player	1.4	0.8	3.5	3.1	4.1	1.2
TV Set Color, 20”	3.7	2.3	9.5	8.4	11.2	3.2
Fluorescent Lamp	16.2	10.1	41.7	37.0	49.3	14.1
Rice Cooker, 1-liter	0.9	0.6	2.3	2.1	2.7	0.8
Water Dispenser	0.7	0.5	1.9	1.7	2.2	0.6
Refrigerator, 8-cu. Ft.	2.7	1.7	7.0	6.2	8.2	2.3
Personal Computer	1.8	1.1	4.6	4.1	5.5	1.6
Laptop	6.8	4.2	17.4	15.4	20.6	5.9

3.4. Climatological Normals in the Leyte province

The climatological normals of Tacloban and Maasin weather stations, as shown in Figure 5 and 6, is a computed table of weather situation of two locations for a consecutive 30-year period. Column 2 and 3 of the table shows the rainfall amount and the number of rainy days in a month. Columns 3 and 4 are the daily temperatures recorded early in the afternoon and before sunrise, respectively. Column 5 is the average of the maximum and minimum temperatures. Column 11 is the relative humidity while column 16a and 16b are the number of days with thunderstorm and with lightning, respectively.

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CLIMATOLOGICAL NORMALS

STATION: **TACLOBAN CITY, LEYTE**
PERIOD: **1991 - 2020**

LATITUDE: **11°13'32.21"N**
LONGITUDE: **125°01'29.92"E**
ELEVATION: **2.711m**

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16a)	(16b)
MONTH	RAINFALL		TEMPERATURE						VAPOR PRESS. (mbs)	RH (%)	MSLP (mbs)	WIND		CLOUD AMT. (okta)	NO. OF DAYS W/	
	AMOUNT (mm)	NO. OF RD	MAX (°C)	MIN (°C)	MEAN (°C)	DRY BULB (°C)	WET BULB (°C)	DEW POINT (°C)				DIR (16pt)	SPD (mps)		TSTM	LTNG
JAN	367.1	18	29.5	23.8	26.7	26.1	24.3	23.6	29.2	86	1011.1	NW	2	6	2	1
FEB	278.4	15	30.2	23.7	26.9	26.3	24.2	23.4	28.9	84	1011.5	NW	2	6	2	1
MAR	233.3	14	31.0	24.1	27.6	27.0	24.7	23.9	29.7	83	1011.0	SSE	2	5	3	1
APR	124.0	12	32.0	25.0	28.5	28.1	25.6	24.7	31.2	82	1010.1	SSE	2	5	6	3
MAY	143.4	11	32.5	25.6	29.0	28.7	26.2	25.4	32.5	83	1008.9	SSE	2	5	13	9
JUN	210.8	15	32.1	25.4	28.7	28.4	26.0	25.3	32.2	84	1008.5	SSE	2	6	13	9
JUL	188.4	15	31.9	25.1	28.5	27.9	25.7	24.9	31.6	84	1007.9	NW	1	6	14	11
AUG	156.1	12	32.3	25.3	28.8	28.2	25.7	24.9	31.5	83	1007.8	NW	1	6	12	10
SEP	186.1	13	32.1	25.1	28.6	28.0	25.7	25.0	31.7	84	1008.2	NW	1	6	14	13
OCT	214.6	16	31.7	25.1	28.4	27.7	25.6	24.9	31.7	85	1008.5	NW	1	6	15	12
NOV	288.0	19	31.0	24.8	27.9	27.2	25.4	24.8	31.4	87	1009.0	NW	2	6	9	6
DEC	450.4	22	30.1	24.4	27.3	26.6	24.9	24.3	30.5	88	1009.8	NW	2	6	5	3
ANNUAL	2,840.6	182	31.4	24.8	28.1	27.5	25.3	24.6	31.0	84	1009.3	NW	2	6	108	79

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Figure 7. Climatological Normals of Tacloban City from 1991-2020

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CLIMATOLOGICAL NORMALS

STATION: **MAASIN, SOUTHERN LEYTE**
PERIOD: **1991 - 2020**

LATITUDE: **10°08'20.43"N**
LONGITUDE: **124°51'37.44"E**
ELEVATION: **72m**

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16a)	(16b)
MONTH	RAINFALL		TEMPERATURE						VAPOR PRESS. (mbs)	RH (%)	MSLP (mbs)	WIND		CLOUD AMT. (okta)	NO. OF DAYS W/	
	AMOUNT (mm)	NO. OF RD	MAX (°C)	MIN (°C)	MEAN (°C)	DRY BULB (°C)	WET BULB (°C)	DEW POINT (°C)				DIR (16pt)	SPD (mps)		TSTM	LTNG
JAN	289.2	16	29.5	23.2	26.3	26.0	24.1	23.4	28.8	85	1010.7	NE	2	6	1	8
FEB	198.2	12	30.1	23.2	26.6	26.3	24.5	23.9	29.1	85	1010.7	E	2	5	1	6
MAR	142.7	10	31.0	23.6	27.3	26.9	24.5	23.6	29.1	82	1010.1	E	2	5	1	6
APR	71.9	7	32.1	24.3	28.2	27.8	24.1	24.1	28.3	76	1009.4	E	2	4	2	6
MAY	95.3	8	32.6	24.7	28.7	28.4	25.7	24.7	31.2	80	1008.8	E	2	4	5	14
JUN	160.6	11	31.7	24.5	28.1	27.9	25.4	24.5	30.9	82	1008.8	E	2	5	5	16
JUL	209.6	14	31.1	24.2	27.6	27.5	25.2	24.4	30.6	83	1008.7	SW	2	6	7	16
AUG	202.6	14	31.1	24.3	27.7	27.5	25.3	24.5	30.8	84	1008.9	SW	2	6	8	15
SEP	236.6	14	31.1	24.1	27.6	27.4	25.1	24.3	30.5	84	1019.2	N	2	6	8	16
OCT	232.8	15	31.1	24.0	27.6	27.3	25.1	24.3	30.4	84	1009.1	N	2	5	8	16
NOV	213.7	15	30.8	23.8	27.3	27.0	24.8	24.0	29.9	84	1009.2	N	2	5	4	12
DEC	285.6	17	29.9	23.5	26.7	26.4	24.4	23.7	29.3	85	1009.7	N	2	5	2	10
ANNUAL	2,338.8	153	31.0	23.9	27.5	27.2	24.8	24.1	29.9	83	1010.3	E	2	5	52	141

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Figure 8. Climatological Normals of Maasin City from 1991-2020

CONCLUSION

The increasing demand on energy consumption could not be answered by creating a new energy resource, but by introducing efficient appliances and devicesor through utilization of existing and available resources. Small-scale and unutilized water resources such as rainwater could be a source for energy generation. Rainwater becomes waste and down the drains causing flooding especially in urban areas and during rainy seasons. Rainwater is a readily available source of energy that can meet the rising need for energy. This energy could supply power for efficient devices introduced nowadays. Rainwater harvesting introduces a new energy source. This idea is for independent and on-site energy generation both for urban and rural area application. The equivalent energy generation of rainwater harvesting is categorized as a small-scale energy source equivalent to a micro-hydropower capacity based on DOE's classification. Using an initial water head (height of the building) of 5 meters, average floor area of buildings and rainfall precipitation of 215.81 mm in the Leyte province, the energy equivalent of utilizing rainwater harvesting are the following: 252.62 Whr up to 1,043.19 Whr for residential buildings, 925.70 Whr for commercial buildings, 1,233.04 Whr for institutional buildings, and 352.49 Whr for agricultural buildings. The energy equivalent from different types of buildings can be used to power-up common household appliances. Furthermore, the energy generated from rainwater can power common household appliances for hours. This small-scale power generation is essential, though small as compared to other on-site power sources, in minimizing the power demand from the conventional energy sources. The continuous development of technology in harnessing rainwater energy will hold a bright future for the Leyte province.

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