INTEGRATING STORAGE SIZING AND WATER TREATMENT FOR RAINWATER HARVESTING IN THE PHILIPPINES

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Abstract :Rainwater harvesting technologies refer to methods of collecting and storing rainwater to supplement the demand of the population. The design of its components, specifically the storage component, is highly dependent on the rainfall pattern for a given locality. The main objective of the study is to develop guidelines that would generate water for potable and non-potable applications through rainwater harvesting. In this study we analyzed the rainfall patterns of each climatic region by considering representative areas such as Sangley (Cavite), Daet (Camarines Norte), Tanay (Rizal), and Davao City (Davao del Sur) to determine the recommended tank size for each region. Using the Yield-After-Spill Algorithm, we found out that rainwater harvesting systems are more reliable in Daet (Type II Climate) and least for Sangley (Type I Climate). Reliability curves are made to aid in decision making. For potable applications of harvested rainwater, the study proposed to incorporate the following treatment technologies: first flush diverters, neutralization and filtration, and disinfection. To be able to define the "shifting point" – when is it economical for a user to use whole of his roof area than just half of it, we studied the harvesting system of UP BRS Model House. We found out that whatever demand we satisfy and whatever study area we consider, it will be economically advantageous to use the whole roof area if the recommended tank size is 600 L or larger. Finally, we can promote RWH technology through education and awareness programs, demonstration projects, and networking between government and non-government institutions.

Key words :Rainwater harvesting; reliability; yield-after-spill algorithm

1 INTRODUCTION

1.1 Background

Food supply problem is one of the five major environmental problems that the world is facing today. Water shortages and groundwater depletion are identified as two important issues associated with this problem. Inefficient use of water resource and ineffective water allocation yields to water shortages which require research on possible alternative resource that could help satisfy the requirement of the population for adequate water supply.

Rainwater harvesting (RWH), in general, refers to methods (e.g. simple and engineered) employed to collect rainwater through catchment systems, divert them through gutters to a storage tank to provide water for specific applications such as toilet flushing, gardening, bathing, dishwashing, cooking, and drinking. Rainwater harvesting system usually consists of three major components: catchment system, conveyance system, and storage tank. Designing storage tank is a vital part since it is considered as the most expensive part of a rainwater harvesting system. Thus, much concern is required to determine the storage tank size applicable for a given set of conditions usually demand, supply, and roof area (Ward, 2010).

To be able to promote the technology, we need to identify and supply the users with the advantages of the system over the current "lined system" of water distribution. Its advantages include ease in terms of installation, operation, and maintenance with readily available construction materials. In comparison with the current system, through rainwater harvesting, water can be supplied at the point of consumption thus, owners are in full control of the technology. In terms of water quality, harvested rainwater can directly be used in non-potable applications such as gardening and toilet flushing. In terms of environmental impacts, as compared to other sources, rainwater harvesting technology pose lesser or no damage at all for the environment since existing structures such as domestic houses will only be retrofitted. Its disadvantage relies mainly on the randomness of the rainfall pattern thus the demand of the user will not always be met.

In terms of its economic value, rainwater harvesting can be costly and often, systems that could meet a household water demand are unaffordable. Since costs are mainly concentrated on the storage tank, there is a need to ensure that tanks and effective roof area are matched properly to meet the water demand at the least cost (Figure 1). But if sized properly, it will yield acceptable and economically justified technology.

Of all the sources of water, rainwater is among the cleanest. Its quality diminishes depending on the quality of the atmosphere, the catchment and conveyance systems, and storage tank. At present, harvested rainwater is used mainly to supply the demand of the population for non-potable water but through adequate research on existing treatment techniques, it is possible for rainwater harvesting technology to supplement our needs for potable applications. Potable applications include drinking, cooking, bathing, and dishwashing. Non-potable applications include toilet flushing, fire suppression, household cleaning, gardening, laundry washing, pool/pond filling, and vehicle washing (Crawford).

1.2 Objectives

The study aims to develop guidelines for a system that would generate water for potable and non-potable applications through rainwater harvesting. It aims to answer questions like "What tank size is recommended for a particular location that would provide N liters of water per day and that is R% reliable?" Different study areas will be chosen to represent the four climatic types of the Philippines. Given the parameters such as daily rainfall (supply), daily demand, and roof area, the relationship between tank size and reliability will be made to help users in deciding what storage size fits their sets of parameters and how reliable that tank size is. This decision-making process will be assisted by economic analysis through consideration of existing rainwater harvesting system in University of the Philippines – Diliman. To account for potable applications, water treatment techniques will be suggested in consideration of their effectiveness and costs. This study also aims to establish some methods to promote rainwater harvesting in the Philippines.

1.3 Significance of the Study

Rainwater is considered as a valuable resource that is currently underused and rainwater harvesting can be a means of minimizing pressure on water sources. But, lack of progress in rainwater harvesting is very observable due to lack of experience and absence of well-run demonstration sites (Ward, 2010).

Rainwater harvesting (RWH) technology is not that popular in Philippine context. Some users blindly select tank size to harvest rainwater creating an inefficient system unable to supply rainwater for the whole year. Others consider the "one size fits all" as the governing principle for tank sizing. In this approach, the whole area is considered as one homogeneous entity in the design. However if the parameters such as roof area, demand, and rainfall data are considered, their impacts on tank size should not be neglected.

In general, a house owner who can be a user for rainwater harvesting has very little or no guidance at all when selecting the rainwater tank. There are no set guidelines to select the optimum tank size for the Philippines that consider the varying rainfall for each climatic region, catchment area, and demand or type of end use. Also, more of the researches on this technology focus on large-scale systems; only few discuss the potential of RWH for small-scale systems such as residential areas.

Rainwater harvesting poses significant solution to water shortages. RWH can provide water at or near the point where water is needed as opposed to the current "life-line" situation. Hence, it breaks the consumer's reliance on a water supplier. Aside from its significance on water savings potential, RWH can reduce storm drainage load and excessive flooding.

Harvested rainwater can be used for non-potable purposes such as garden use, toilet flushing, and washing clothes. Also, it can support the users need on potable water such as a drinking source, which requires water of better quality. Roof rainwater is often of better quality, soft, and is very ideal for washing.

Results of this study can be used to optimally size RWH in situations where water users do not have access to computers and RWH Tank Size Calculators available in the internet. RWH can be costly and systems that meet a household's water needs are often expensive. It creates a necessity to maximize the use of rainwater through optimizing storage.
Also, this study may serve as a first step to enhance promotion of rainwater harvesting through our government and non-government institutions.

1.4 Scope and Limitations

Storage is considered as the most expensive part of a Rainwater Harvesting Facility. Proper determination of tank size based on factors such as rainfall, roof area and characteristics, and demand is necessary to identify the most economically feasible storage tank size. Utilizing commercially available tank sizes would mean varying reliability and cost. Therefore, it is a requirement to provide details on this relationship. Rainwater Harvesting must be engineered in order to produce water of varying quality from non-potable to potable applications. An incremental increase in quality means greater cost. Basically, economic analysis of design of water treatment will be based on what demand is expected and what quality the user prefers.

The study is limited to considering only the four study areas. It assumed that those areas represent the type of climate of their neighboring regions. The amount and length of rainfall used is limited to what is obtainable by Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA) thru its Hydrometeorological Data Section. It is assumed that the owner has his own access to other parameters namely demand and roof area. This study is made for low-cost housing, with A-Frame Roof. Any result shown in this paper is only applicable for those sharing the same conditions and criteria as low-cost housing. Also, the study is limited to providing the user with treatment methods that the author thinks are relevant to achieve a certain water quality. No models have been made and tested during the entire duration of the study. In terms of economic analysis, the study considered the UP Building Research Service (BRS) Model House to come up with a cost analysis. It had been retrofitted in 2008 by Fajardo and Oliva in their study on Basic Components of a Rainwater Collection System for Household. In terms of material selection, this model utilized the cheapest and readily available materials in the market. It must be noted that prices of materials may vary depending on the location. UP BRS Rainwater Harvesting Model has been used because it is considered as one of the economical ways of storing and harvesting rainwater.

1.5 Framework of the Study

The processes involved in the implementation of this study is shown below.

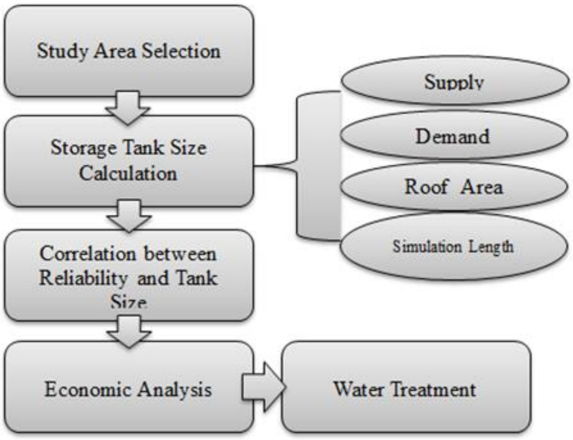

Figure 1 Framework of the Study

2 METHODOLOGY

2.1 Study Areas

Figure 2 Study areas representing the four climatic regions of the Philippines

Figure 2 shows the four areas chosen – one per each climatic region. These are Sangley, Cavite (Type I), Daet, Camarines Norte (Type II), Tanay, Rizal (Type III), and Davao City, Davao del Sur (Type IV).

2.2 Storage Tank Size Calculation

In calculating the required storage, we considered the following variables: supply (rainfall data); demand estimate, roof area and runoff coefficients. Each of these factors are considered vital to achieve accurate results.

2.2.1 Rainfall Data

Discretized six hourly rainfall were made available through Hydrometeorological Section of Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA). Varying length of rainfall were made available and used throughout the study.

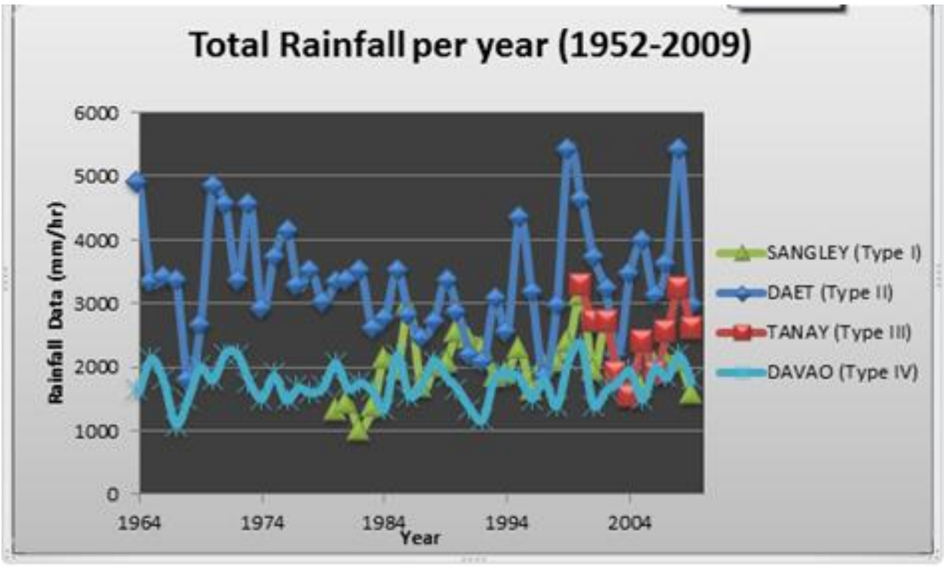

Figure 3 Comparison of total yearly rainfall recorded in the four stations

2.2.2 Demand Estimate

From the study of Inocencio, et. al., we found out that the recommended basic requirement is 54 L/capita. If we assume a household with four members, the total demand that will be used in the study is 216 L/day, approximated to 200 L/day.

However, this is just an assumption used in the study. In the event that the user is knowledgeable of their consumption, he is free to input his own data. The value shown is just used to simulate the harvesting system in case the demand roughly equals 200 L/day.

2.2.3 Roof Area and Runoff Coefficient

We assumed that our roof satisfies the requirement for rainwater harvesting that is, there is no need to retrofit the roof and its gutters. We have only to install our conveyance and storage system. For a family of four, we assumed a house roof area to be 100 m2 and its roofing material is of GI sheet type. Hence, we will use 0.90 for the run-off coefficient.

Table 1 Proposed Basic Water Requirement

Activity	**Proposed Requirement (liters/capita/day)**
Drinking	2.00
Personal Hygiene	23.00
Showering/bathing	
Hand/face washing	
Brushing of teeth	
Sanitation Services	20.00
Urinal/toilet flushing	
Toilet cleaning	
House cleaning	
Cooking and Kitchen	4.00
Food Preparation	
Dish washing	

Laundry	5.00
Total	**54.00**

2.2.4 Simulation Method

Given below is a sample spreadsheet used for simulating the rainwater harvesting system. For instance, consider this worksheet done solely for Tanay, Rizal. We first define the variables used. DT is the estimated demand; VT is the volume of water available at the tank at the start of time T; YT is the yield calculated using the YAS algorithm; c is run-off coefficient; I is the daily rainfall obtained from PAGASA; A is the roof area; QT is the discharge calculated using Rational Formula; and S is the assumed storage tank size. YAS Algorithm is performed for each time step for all the data available. In terms of Reliability, a value of 1 is given if the current volume of the tank satisfies the demand. In symbols, VT > D. Otherwise, value of 0 is given.

Date	DT	VT	YT	c	I	A	QT	S	Reliability
1-Jan-00	200	180	0	0.9	2.00	100	180	1000	0
2-Jan-00	200	0	180	0.9	0.00	100	0	1000	0
3-Jan-00	200	0	0	0.9	0.00	100	0	1000	0
4-Jan-00	200	0	0	0.9	0.00	100	0	1000	0
5-Jan-00	200	0	0	0.9	0.00	100	0	1000	0
6-Jan-00	200	0	0	0.9	0.00	100	0	1000	0
7-Jan-00	200	126	0	0.9	1.40	100	126	1000	0
8-Jan-00	200	0	126	0.9	0.00	100	0	1000	0
9-Jan-00	200	0	0	0.9	0.00	100	0	1000	0
10-Jan-00	200	180	0	0.9	2.00	100	180	1000	0
11-Jan-00	200	0	180	0.9	0.00	100	0	1000	0
12-Jan-00	200	0	0	0.9	0.00	100	0	1000	0
13-Jan-00	200	0	0	0.9	0.00	100	0	1000	0
14-Jan-00	200	0	0	0.9	0.00	100	0	1000	0

Figure 4 Example of a Simulation in a Spreadsheet

2.3 Water Treatment

In consideration of both potable and non-potable applications of harvested rainwater, we consulted several literatures that discuss the applications of different water techniques to rainwater harvesting. We analyze each item and technique in consideration of the initial quality of harvested rainwater.

2.4 Economic Quality

A relationship of how cost varies with tank size and roof area using the information obtained for the UP BRS Model is made to generalize the expected cost for any rainwater harvesting facility. This general relationship is vital for the users to have an idea of the optimal rainwater tank size – that is, at what tank size will they benefit more (high reliability) but at the least cost possible.

We provide further analysis to determine at what storage tank size a user will be recommended to shift from half-area utilization to using the whole roof area. For an A-Frame or gable roof system, there are two options for rainwater harvesting. First is utilization of just one side of the roof system. In this case, a gutter can be installed in just one side to allow collection of rainwater. This means that only half of the roof area will be used for rainwater harvesting. The second option is to utilize the whole area and thus, it will require collection through the two gutter systems. Given that the half-area utilization will require a lower initial investment, our problem is to determine when it is economically justifiable to shift from half to whole area utilization. The simulation presented was ran for A = 50 m2 and A = 100 m2. The reliability resulting from these independent simulations are plotted with cost as their dependent variable. The point of intersection of the two graphs had been identified and considered as the “shifting point”.

3. RESULTS AND DISCUSSION

3.1 Storage Tank Sizing

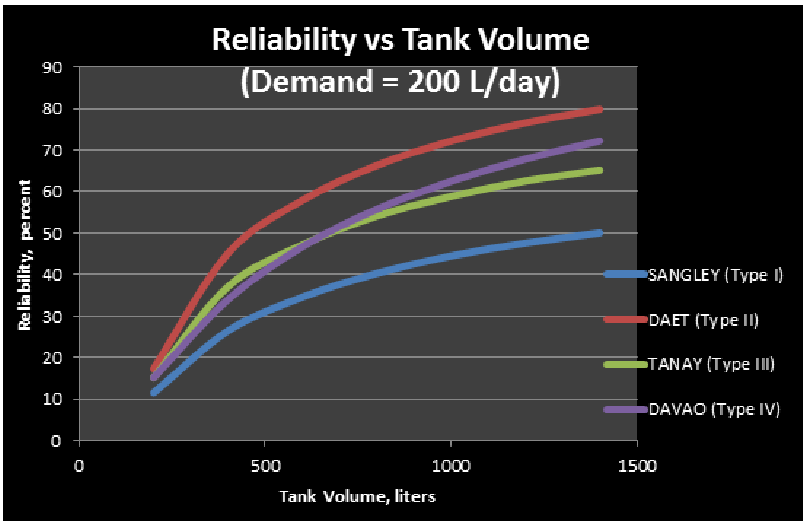

Figure 5 Reliability curves for each station (same demand, roof area, and runoff coefficient)

The following assumptions were made as requirements for the simulation: Demand is 200 L/day; Roof Area = 100 m2; Runoff's coefficient: 0.90; and Storage size increments: 200 L. This is maintained constant for all the study areas. Hence, the variable for the simulation is the rainfall data used. Using the YAS Algorithm, we found out that in general, Daet, as a representative of regions with Type II climate, gives the most reliable tank size if the four stations are compared. This is followed by Davao (Type IV), Tanay (Type III), and least reliability is observed for Sangley (Type I). Since the only variable used in the simulation is the rainfall data, these differences in the observed reliabilities will only be accounted to varying climate for each study area. Rainwater harvesting is more reliable for places where rainfall is well distributed throughout the year similar to types II and IV.

3.2 Water Treatment

The proposed treatment for harvested rainwater includes pretreatment, neutralization, filtration, and disinfection.

First Flush Diverters and Leaf Guards are required for pretreatment purposes. The first flush diverter will be designed as stated in Fajardo and Oliva's*Design Guidelines of Rainwater Collection System for Household Usage.*

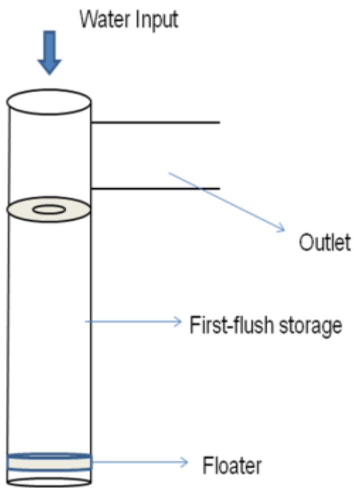

Figure 6 First Flush Diverter

To determine the size of the first-flush storage, we implement the recommendation according to the Texas Water Development Board's Texas Manual on Rainwater Harvesting since there is no any developed method for doing so. According to this manual, in areas where impurities are limited to just dusts or birds' droppings, we estimate the size of the diverter to be 0.41 liters per square meter of collection surface. The quality of water after this stage is sufficient for gardening and toilet flushing applications. These applications do not require any treatment procedure.

For dishwashing, laundering, and bathing, higher quality is required. Hence, we propose the following water treatment techniques – neutralization and filtration.

Neutralization is required to raise the pH of harvested rainwater given that it is naturally acidic. Acidic harvested rainwater may result to corroded metals. We recommend using PVC (plastic) pipes instead of corrodible conduits. Listed on Table 2 is the recommended amount of alkali reagents required to neutralize 1000 gallons of water. It must be added at periodic intervals, preferably once every week. If however, there is little or no fresh rainwater collected during a given week, addition of reagents might not be necessary (Young).

Table 2 Recommended amount of Neutralizing agent to raise the pH of harvested rainwater

Reagent	Chemical Formula	Amount required to neutralize 1000 gallons of rainwater
Limestone	$CaCO_3$	2 oz.
Quick Lime	CaO	1 oz.
Hydrated Lime	$Ca(OH)_3$	1 oz.
Soda ash	$NaCO_3$	1 oz.
Caustic Soda	$NaOH$	1.5 oz.

The Filtration technology to be recommended in this study is based on Kiran, et. al. study entitled, *Feasibility of Collecting Rainwater at NTU (Nayang Technological University).*

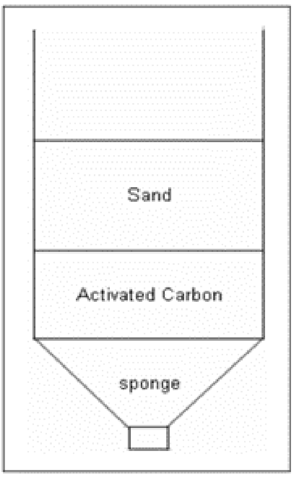

Figure 7 Filtration with varying media – sand, activated carbon, and

This filter is designed to improve the pH, turbidity, and remove impurities. Two general filtration techniques are coupled here to design the system. These are mud-pot and activated carbon filter systems. The proposed system consists of three varying layers – a layer of sand, activated carbon, and sponge. Sand layer is significant primarily because it filters larger solid particles present in the rainwater. This may be further improved by considering multiple layers of sand with varying grain sizes. On the other hand, the activated carbon layer contains a highly porous zeolite, allowing this layer to capture very fine particles that have passed through the sand layer. Furthermore, it has a capability of adsorbing heavy metals and ammonium. It removes also organic contaminants and foul odors. The sponge at the bottom filters off more particles in the rainwater. Sponge acts as a stopper, preventing the sand and the activated carbon to go through with the water. This enables water to spend more time through the layers above.

If rainwater will be used for potable applications such as drinking and cooking, we need to introduce disinfection methods

In this study we propose two disinfection methods. First is Solar Disinfection. In this method, clear plastic or glass bottles are filled with water and then, is exposed to sunlight. This destroys most germs that cause disease. It must be noted that the temperature of the water must not reach as high as 50 oC. For tropical regions, like the Philippines, we need to expose our cleared bottles filled with water under the sun for five hours around midday. If, the water is cloudy, two days is required. We fill the bottle three-fourths full and vigorously shake it to speed up the process.

We will incorporate disinfection through boiling with this process to further treat the harvested rainwater. Boiling is a traditional method of treating water that can kill all germs that cause disease. For this method to work, water must be brought to a rolling, bubbling boil. It is required to boil harvested rainwater for one to three minutes. One disadvantage of this method is that, it will make the water taste flat. It can be fixed by shaking the water in a bottle or adding a pinch of salt for every liter of water boiled.

It is expected that after doing the processes mentioned above, the quality of water is within the standards for drinking water. However, we require that test be done for the treated water to determine if indeed, it is safe to drink. Tests include but are not limited to pH, turbidity, and microbiological tests.

3.3 Economic Analysis
Shown n Table 3 is the estimated cost of the UP BRS Model House along Magsaysay St., UP Diliman Quezon City.

We use those values listed above to come up with an estimate equation relating the total cost of a rainwater harvesting system. We identify the major variables as tank size and roof area. A factor of safety of 1.2 is used for estimation because of other considerations that may not been taken into account correctly by the researcher. Hence we have the following equation:

$$C=10S+30A+1500 \tag{1}$$

whereC is the total cost in pesos, S is the storage size calculated using the simulation, and A is the area of the catchment system

We use this equation to plot cost vs. reliability for a given demand. For instance consider, the plot shown below which considered two roof areas, 50 and 100 sq. meters.

Table 3 Cost Estimation of a Rainwater Harvesting System

Quantity	Item Description	Unit Price	Total Price
3	Plastic Tank	550.00	1650.00
8	3 x 10 Dragon PVC Pipe	180.00	1440.00
1	Heltex Solvent Cement 100 cc	70.00	70.00
7	3" 90 deg Dunhill Elbow	44.00	308.00
2	3" Tee Dunhill Elbow	48.00	96.00
3	Faucet Hose	170.00	510.00
1	1/2 x 10 Moldex Pipe	70.00	70.00
2	1/2" Moldex F. Adaptor	11.00	22.00
6	1/2 x 4 Amazon Screen per meter	115.00	690.00
3	Labor	400.00	1200.00
2	1/4 x 2 Angle Bar (per 6 m)	560.00	1120.00
2	16 mm Deformed Bar (per 6 m)	316.00	632.00
2	Steel works	400.00	800.00
TOTAL			**PhP 8608.00**

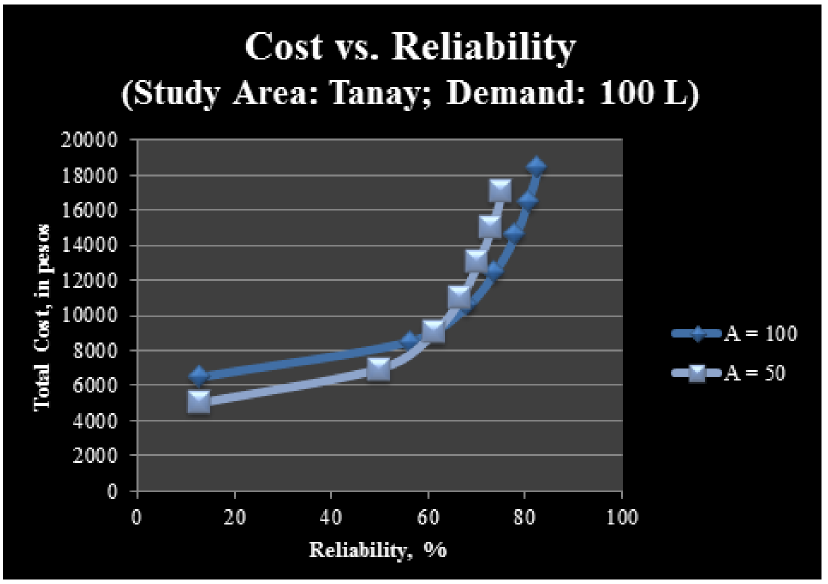

Figure 8 Cost vs. Reliability for 50 and 100 sq. meter roof

We plotted cost versus reliability computed for each storage size (interval of 200 L). We considered two roof areas, 50 m2 and 100 m2. We identify at what point a user will shift from 50 m2 to 100 m2 area for utilization. This is the intersection of the two graphs. In this example it is identified as the point with reliability at approximately 60 %. This corresponds to a tank size between 400 to 600 L. But since we are considering tank sizes in multiples of 200 L, we recommend using 600 L for this condition.

In this study, we found out that for any study area and for any demand, a minimum of 600 L tank size indicates that it is more economical to utilize the whole roof, 100 m2 rather than half of it.

3.4 Recommended Procedures for Technology Dissemination

To promote rainwater harvesting in the Philippines, we propose installation of demonstration projects, promotion through education and public awareness programs, training programs, research and development, and proper networking between government and non-government institutions.

4. CONCLUSIONS

1) Rainwater harvesting is an acceptable alternative source of water for all applications that we can think of including gardening, toilet flushing, bathing, washing, cooking, and drinking.
2) A simple rainwater harvesting is composed mainly of a catchment system, conveyance system, and storage however concentration is more on the storage.
3) Sizing depends on the following factors: demand, supply, roof area, and length of simulation.
4) We considered four study areas to account for the variability in terms of climate of the provinces in the Philippines. Of these areas, rainwater harvesting is most reliable for Daet and least for Sangley. This is mainly due to the nature of rainfall recorded in Daet..
5) Generally, rainwater is a clean water source. However, as it is being transported from catchment to storage, it gets contamination decreasing its quality. Hence, we proposed the following methods to address water quality problems. Leaf guards and first flush diverters are required to initially remove large debris from the harvested rainwater. We introduced neutralization by adding chemicals and filtration through a system with varying media – sand, activated carbon, and sponge. If potable applications are required, such as cooking and drinking, disinfection through solar disinfection and boiling is required. Harvested rainwater up to this point need to be tested first before anyone is allowed to drink it.
6) Using the UP BRS Model, we identified that the cost of retrofitting amounted to P 8,608.00. We used this data to provide a general relationship between cost and two other variables – roof area and tank size. We assumed a linear relationship because we have inadequate sources of information to assign with any other type of relationship. We used this equation to plot cost and reliability. We used this graph to identify at what point a user will shift from a 50 m2 to 100 m2 roof area. This turning point is identified to be constant at 600 L tank size.
7) Lastly, we have identified some ways on how we can promote rainwater harvesting as an alternative water resource in the Philippines. These include education and awareness programs, demonstration projects, and networking between government and non-government institutions.

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