World Academics Journal of Engineering Sciences
Vol.8, Issue.2, pp.01-07, June (2021)

Research Paper

E-ISSN: 2348-635X

Economic Viability Assessment of Rainwater Harvesting System for Meeting Non-Potable Water Demands in Metro Manila

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Available online at: www.isroset.org

Received: 08/Jun/2021, Accepted: 20/Jun/2021, Online: 30/Jun/2021

***Abstract* —** Rainwater Harvesting has its reputation growing worldwide as it is one of the most promising solution to water stress, such as the drought in Australia and groundwater contamination in Cambodia. The success of its installation and execution requires extensive planning and a large sum of money. It is critical to determine if it is a viable project, therefore, conducting an economic viability assessment is highly beneficial. Fixed and variable parameters were determined and combined to create a 12-scenario hydraulic and financial model. The researchers gathered these parameters data input through conducted online surveys for the actual household conditions and the costs of materials for the RWHS components were estimated online. These gathered parameters data were processed, modelled, and simulated using a spreadsheet-based modelling software, RainCycle Advanced 2.0. In the 65-year simulation of multiple scenarios with limited catchment areas, the results revealed negative savings and no payback period, as well as an indirect relationship between the water demand met and the number of occupants. The findings indicate that in ideal circumstances, a maximum savings of 121,000 Php can be achieved, demonstrating RWHS's potential. No payback period was obtained due to the inexpensive mains-water cost matched against a very costly upfront spending in the RWHS components. However, it is still important to initiate measures to encourage practices of saving water therefore, a subsidy program for RWHS installations should be explored by the government and the water concessionaires.

Keywords*— Rainwater Harvesting, Economic Viability, Water Deman, Raniwater, Metro Manila*

I. INTRODUCTION

The Philippines experiences an average of 2,400 millimeters of precipitation annually – one of the world's highest according to a 2019 Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) data. In Metro Manila, the climate is monitored in PAG-ASA Climate Station located in Port Area. The city's annual mean temperature is 28.2°C, ranging from 25.2 to 31.2°C. The monthly rainfall recorded at 486 mm with 22 rainy days mostly occurring during the wet period from July and August [1].

With this high amount of annual rainfall, it was a surprise that water shortage was still an issue in the country. March 2019 was when a water supply crisis hit the capital of the Philippines and affected most of Metro Manila. Therefore, the utilization of Rainwater Harvesting System (RWHS) as a supplementary water source could serve an important solution to mitigate the water shortage problems the country faces.

Rainwater Harvesting System (RWHS) or Rainwater Collector System was a method that collects rainwater and stores it in water tanks for domestic and agricultural use, either immediately or in the future. However, despite the positive effects of RWHS, negative connotations plague the reputation of the implementation of this system. RWHS was known to be a capital-intensive investment and yet to be innovated to avoid system inefficiencies. This issue could be addressed by designing or modelling the RWHS economically. Several studies already discussed the economic viability of the RWHS.

Unfortunately, most of the studies related to implementation of rainwater harvesting only focused on either the benefits of installing a RWHS or assessment for the cost-efficiency of the entire system. There had been a lack of studies that correlate all possible benefits, both quantitative and qualitative, and compare it to the direct and indirect costs of the installation. Therefore, this study investigated determining the economic viability of RWHS in the Philippines, particularly in Metro Manila and used the RainCycle Advance 2.0 with Monte Carlo Simulation (MCS).

The Monte Carlo Simulation was a method used to analyze the complex dynamic systems or models with uncertain parameters. It was widely used in finance, economy, and physical science due to its function of assessing risk by predicting possible outcomes for any changes in input in the chosen parameters. With the proper design procedures, future risk could be reduced to a minimum making the system to be more attainable which would eventually lead to the reduction in negative implications and misconceptions about implementing RWHS in the country. To evaluate the economic viability of the installation of a RWHS, the payback period, which is the time where the total investment will be returned in the form of savings, needs to be estimated. For the investment to be more attractive, the said payback period needs to be short. The longer the payback period the more unattractive the investment gets. Payback period is obtained by comparing the total expenditures to the total costs of the project. In this research, the savings were computed as the difference between cost of potable water supplied to the water saved from the system. The potable and non-potable uses of water were considered in this study.

II. RELATED WORK

A study was conducted to present the hydraulic and financial model of a RWHS which used a residential apartment in Ibadan, Nigeria where payback period was estimated, and water savings efficiency was assessed [2].

The results of this study showed that the smallest tank size of 3 cubic meter had the shortest payback period of 18 years, highest monetary savings of $324, and water demand met of 70.1%. The daily water consumption of a typical household in Nigeria shows that 33% of the daily water use is toilet flushing in which harvested rainwater can be used as an auxiliary because it is a non-potable water requirement. It demonstrates the overall available demand that harvested water will serve as a source of water for non-potable needs.

The fixed parameters were catchment surface area, first-flush volume, storage tank volume, pump power rating, pump capacity, UV unit power rating and UV unit operating time while the variable parameters were rainfall profiles, runoff coefficients, filter coefficients, additional inputs, discount rate, electricity cost, mains water cost, water demand, disposal cost, capital cost and decommissioning cost. The variable parameters could assume three possible values classified as high, average, and low values. This will enable the variations in the performance of the system both in financial and hydraulic terms.

The results produced by the RainCycle Advanced 2.0 shows that Mains-only cost is still more expensive than RWH Costs.

III. METHODOLOGY

3.1. Data Gathering and Sample Size

The data gathering was done through survey questionnaires for the key parameters at a household level in terms of (a) number of occupants (b) number of flush toilets (c) water consumption and (d) surface catchment area. However, for more accurate data results, the team utilized Google Earth's measure feature to obtain the average area of residential roofs in Metro Manila. Furthermore, the costs and expenditures for the Rainwater Harvesting System (RWHS), such as the material parts for installation, was canvassed from different hardware stores in Metro Manila to have an updated and more precise data to be used in the analysis. The data gathered were then put in the RainCycle Advance Program to determine the range of suitable tank sizes, cost savings of tanks to choose the optimum size.

The sample consists of middle-class residents of various barangays in Manila City, Philippines. All households in the barangays are to be considered assuming that the households have functioning toilets and can afford a RWHS.

The researchers conducted an online survey to cater a wider range of respondents along various barangays in Metro Manila. To obtain a more realistic data, the survey had at least 100 samples. The survey questionnaire includes the following information (a) the number of occupants per household, (b) number of flush toilets per day, and the (c) estimated floor area. The team utilized Google Forms to gather the needed information.

The Google Earth Measure Tool was used to obtain the surface catchment area.

The aim of this study was to evaluate the economic viability of the Rainwater Harvesting (RWH) system to assess the reliability of RWH in supporting the supply of demand for non-potable consumption by water service companies and as a potential investment at household level in Metro Manila. The economic viability was analyzed using a state-of-the-art computer-based modelling tool – RainCycle Advance 2.0.

3.2. Precipitation Data

The available rainfall depends on the pattern of precipitation, the surface of the catchment area and the loss of water. A continuous 25-year rainfall record for the years 1993-2018 in the Philippines and in areas of Metro Manila was obtained from PAGASA [3].

The precipitation data was gathered from the PAGASA website. Figure 1-3 shows the average annual rainfall from the three (3) rain gauge centers in Metro Manila specifically Science Garden in Quezon City, NAIA, and Port Area Manila.

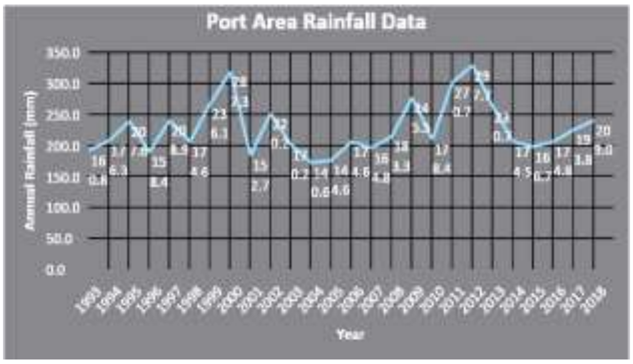

Figure 1: Metro Manila (Port Area) historic annual rainfall depths 1993-2018

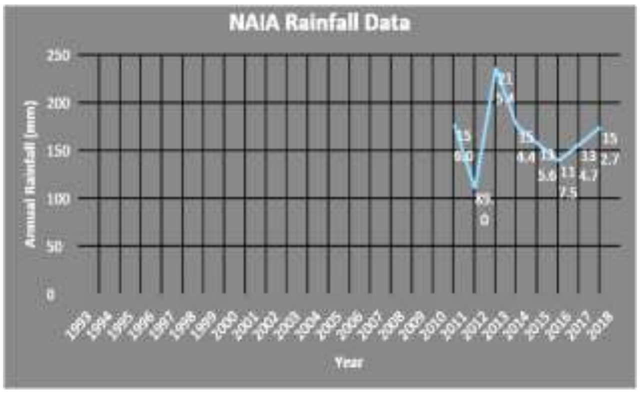

Figure 2: Metro Manila (NAIA) historic annual rainfall depths 1993-2018

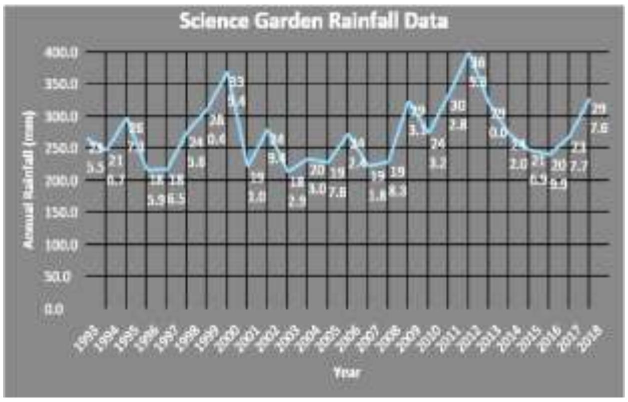

Figure 3: Metro Manila (Science Garden QC) historic annual rainfall depths 1993-2018

3.3. *Water Demand Data*

The collected rainwater was used solely for toilets flushing. Any shortfall in supply will be compensated by mains top-up water. The information on the use of domestic facilities was obtained from the conducted survey questionnaire specifically, the number of visits per person per day. The program also has a default value of 6.0 litres per flush per person and was therefore used. Washing machine uses, garden irrigations, car/vehicle washing were not considered. The parameters gathered were then inputted to the Water Demand Calculator of RainCycle Advance 2.0.

Using the values from Table 1, the resulting total demand per cubic meter per day was found to be 0.288. It is assumed that the water demand was the same for all the days of the year. For the above and below average yearly water demand profiles, 20% was added/subtracted from the average term-time values, respectively.

Table 1: Demand Calculator Parameters

Heading	Item	Value to be used
Occupancy Details	Number of People	6
Frequent Uses		
Toilet Flushing	Volume per flush (liters)	6
	Number of visits per person per day	8

3.4. *Different Scenarios*

Table 2 shows the scenarios that were simulated with the RainCycle Advanced 2.0 and their corresponding data. The parameters that were used as the variables in the scenario were chosen to be the catchment area and number of occupants.

Table 2: Different Scenarios

Scenario	Area of Catchment (sq.m.)	Number of Occupants
1	50	2
2	50	4
3	50	6
4	50	8
5	75	2
6	75	4
7	75	6
8	75	8
9	100	2
10	100	4
11	100	6
12	100	8

IV. RESULTS AND DISCUSSION

4.1. *Survey Results*

From the survey result on the number of occupants in the household, the results lead the researchers to use 2, 4, 6, and 8 occupants in the variable parameters in the scenario modeling. As to the estimated roof area of the respondents' house, the results of the survey on the catchment areas were clustered into three values, 50, 75 and 100 sq. m. to be used as one of the variable parameters in the scenario modelling. As to the number of times they flush daily, 53 from the total of 105 respondents answered that they used the bathroom more than 6 times. As to the respondents' average water bill, majority with 45.7% of the total respondents replied that it is in the range of Php 901 – above. A total of 71.6% of the total respondents said that they agree to consider installing a RWHS, while 25.3% answered "maybe" and the remining percentage responded "no".

4.2. *Simulation Results*

The combined results for the Economic Viability and the Monte Carlo Simulation for scenarios 1-12 shows that within 65 years, all scenarios will have negative savings and therefore, will not have a payback period. No payback period can be attained by the systems in the configuration due to the high capital cost by the RWHS components and the historically cheap water prices in the country. In addition to the economic analysis, the Monte Carlo simulation provided the data that as the number of occupants increase, the water demand met by the system decreases and this is due to the direct increase in the water demand.

4.2.1 Long Term Savings

Figure 4 shows the plot of the long-term savings of all the scenario models in the simulation. The base scenarios or the ones with 2 occupants, proves to be the least viable in terms of economy since they all have negative savings across the 65-year period of the simulation. However, as the number of occupants increase, the long-term savings increase with it as well making it a better investment. Across all scenarios, all configurations start to improve economically at 4 occupants demonstrating better potential in terms of mean savings and maximum savings. The maximum savings are at their peak when the catchment area is 100 sq.m. Both the hydraulic and economic performance of a RWHS is directly correlational to both the catchment area and the tank size. Given the right configuration and the favorable setting, RWHS can potentially save over a period 65 provided that the residential structure has at least 100 sq. m. of roof area and at least 6 occupants. Any value lower than the minimum catchment area or the number of occupants would lessen the overall long-term savings the system can produce and its efficiency.

4.2.2. Payback Period

Figure 5 shows that for the base scenario of the simulation, it will never have a payback period as an investment due to the high upfront cost of the RWHS components and the relatively cheap mains water cost in the country.

4.2.3 Percentage Demand Met

Figure 6 presents the percentage demand met in all scenario models. It is evident that no configuration can ever meet 100% of the non-potable demand of any household due to possible influx of usage or lowered generated volume of rainfall at certain times of the year. Percentage demand met is at its maximum when the occupants are at its minimum thus, revealing a negative proportionality between them. Even if the percentage demand is at its minimum when the occupants are at their maximum number, it is still a positive sign since this means at an increased water demand brought by an increase in occupants, all the reticulated water is used up by more people and is serving its purpose properly. It is important to note that as the occupants increase, the total water demand volume also increases therefore, to be able to cater to a large percentage of it is a good indicator of its usefulness.

The general increase in the percentage water demand met as the roof area or the catchment area increases is also evident in the graph. A larger catchment area leads up to a higher retained and reticulated volume of water and if combined with an appropriately sized tank, will give optimum results in reliability and in efficiency on a consistent basis.

4.2.4 Average Yearly Saving

All minimum savings are losses across all scenario models, this is an indicator of the volatility of the RWHS as an investment considering all factors. As shown in Figure 7, it is still evident that the first scenario is the least optimum configuration among all the scenario models in which it yields losses in the minimum, average, and maximum savings. A similar trend to that of the percentage demand met was recorded in which the yearly savings increase with the number of occupants and the catchment area. In terms of annual savings, the combination of 8 occupants with the catchment area of 75 sq. m. is the optimum configuration for having high yearly returns in the investment made.

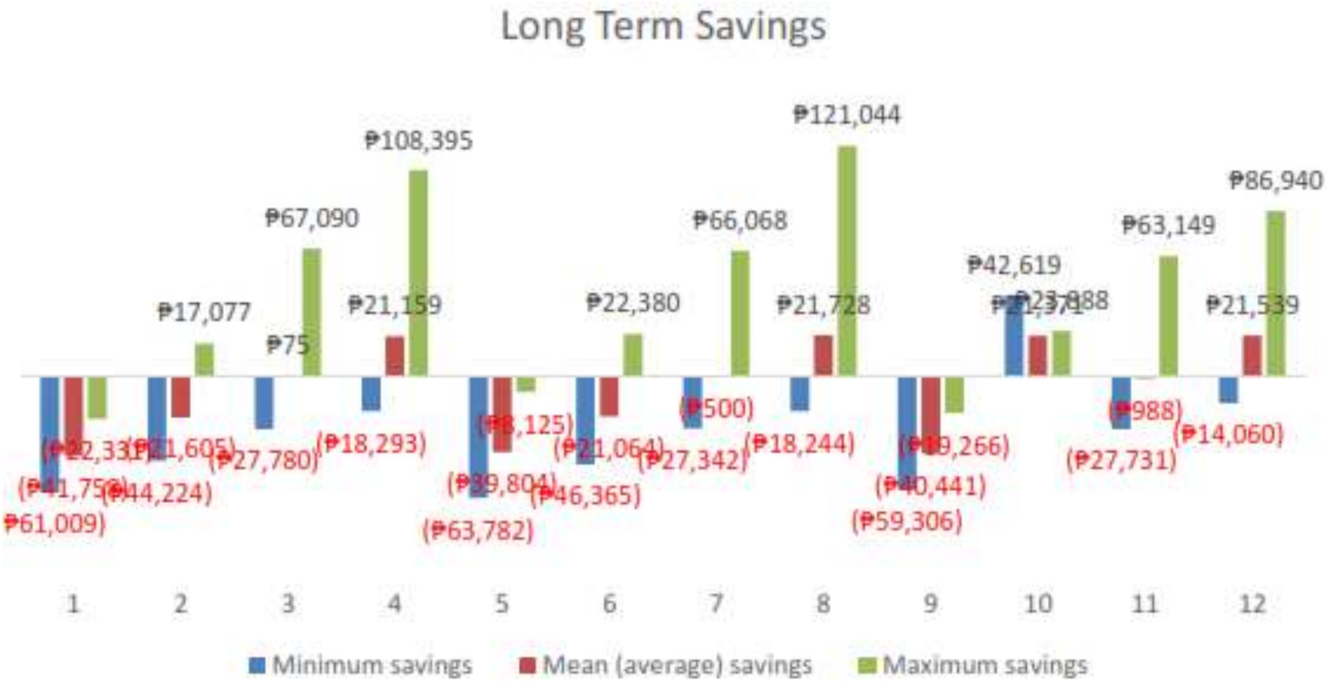

Figure 4: Long Term Savings

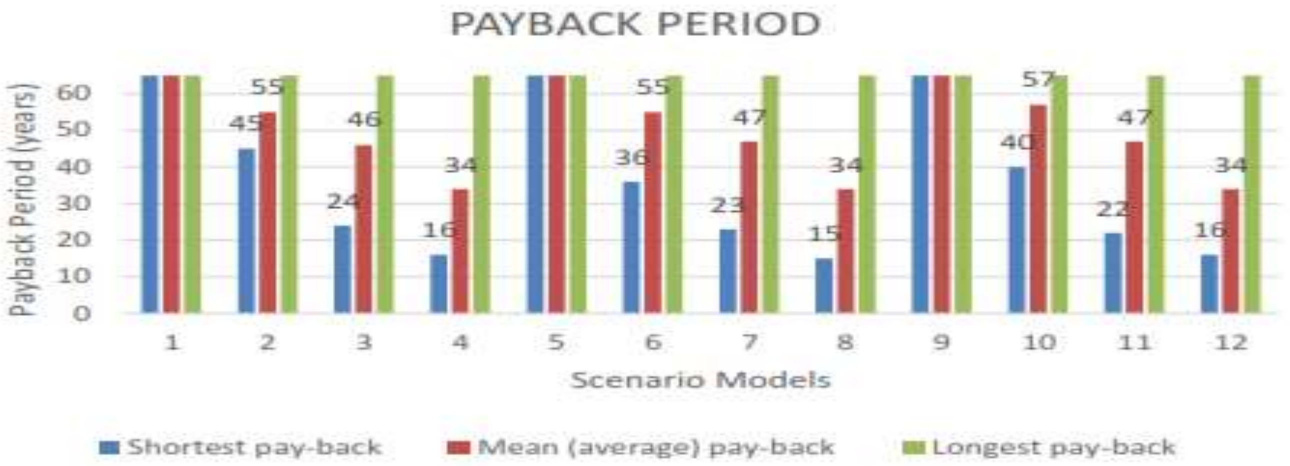

Figure 5: Payback Period

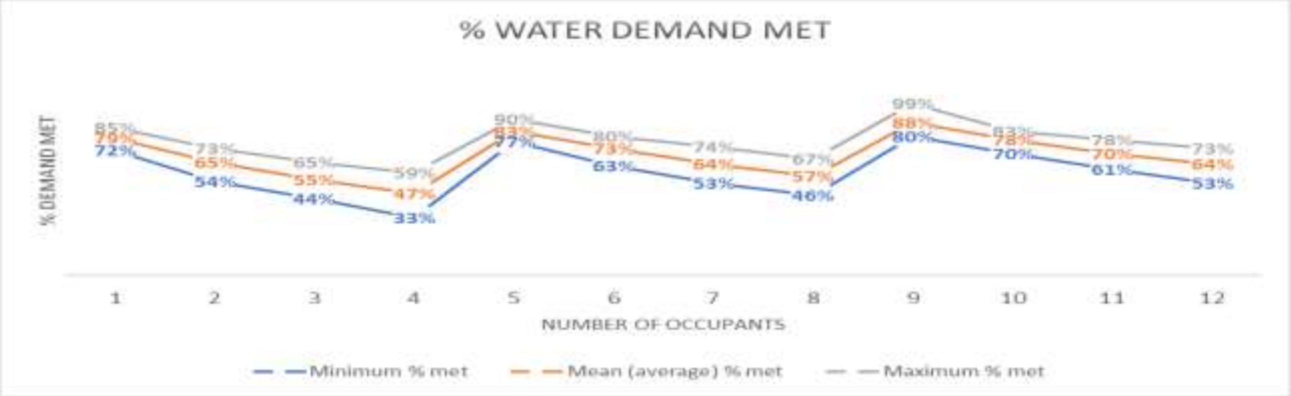

Figure 6: Percentage Demand Met

Figure 7: Average Annual Saving

V. CONCLUSION AND FUTURE SCOPE

Across the 65 years analysis, all of it would have negative savings and would not have a payback period, which rely on two factors namely, the capital cost and the mains water cost. No payback period was attained by the systems in the configuration due to the high capital cost by the RWHS components and the historically cheap water prices in the country.

In addition to the economic analysis, the results shows that as the number of occupants increases, the water demand met by the system decreases. This was due to the direct increase in the water demand of the configuration as well. All configurations started to improve economically at four (4) occupants demonstrating better potential in terms of mean savings and maximum savings. Long-term savings over a 65-year period revealed that the payback period and the mains water cost have an indirect relationship to each other, and high capital cost with low water demand results in little to no savings. However, the maximum savings were at its peak when the catchment area was 100sq.m. To boost the hydraulic efficiency and economic viability of RWHS, larger catchment areas help.

Since the Philippines have one of the most low-cost water prices in Southeast Asia, it was expected to have a very long payback period. If there comes a time where the prices increase, water saving practices of all kinds would be a better investment and would have a bigger impact in providing water supply support. In the meantime, it was important to initiate measures to encourage practices of saving water.

In conclusion, RWH is a viable way of reducing dependency on mains water and, under favorable circumstances, could also provide monetary savings in the long term.

It is recommended that future researchers should use this research as a basis to propose enhancements and an integrated approach in the overall performance evaluation of rainwater harvesting systems.

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AUTHORS PROFILE

Armi Cunanan-Yabut is the Director of the Quality Assurance Office and a faculty member of the Civil Engineering department of Far Eastern University (FEU) Institute of Technology. She pursues her BSCE in Technological Institute of the Philippines and MS in Environmental Engineering and PhD in Environmental Engineering both in Mapua Institute if Technology in 2005, 2010 and 2017, respectively. She is a licensed civil engineer and certified environmental specialist.

Florante D. Poso, Jr., pursue his BSCE in Adamson University, MCE and PhD in the University of Eastern Philippines, in 1996, 2004 & 2008 respectively. He is a Philippine registered civil engineer, registered professional secondary teacher and ASEAN engineer. He had been working for more than 20 years in various fields of civil engineering both in the construction industry and in the academe. At present, working as a full-time professor and OIC Program Director of the Civil Engineering department of Far Eastern University (FEU) Institute of Technology. He worked with Daewoo Engineering and Construction Co., Ltd. as Civil Engineer/Quantity Surveyor for the construction of Safi Independent Power Plant Project in Safi, Morocco.

Mary Rosetem Amorganda is 4th year Civil Engineering Student at FEU – Institute of Technology. She is a former architectural student from Mapua University SY 2013-2014. She then transferred to FEUIT and took up Civil Engineering in 2016 in hopes of graduating with honors and/or become a future top-notcher. She has bagged several top rankings in her classes and acquired the Top 3 among all Civil Engineering Students in 2017. She has also garnered her highest GWA of 3.75 in her 2 years in FEUIT.
Moreover, she has also co-authored in certain papers: (1) Economic Viability Assessment of Rainwater Harvesting System for meeting Non-potable Water Demand in Metro Manila, (2) Easing Traffic Congestion: A Comparison of Roadway Guidelines among Countries, (3) Updated signalized intersection: development of an effective traffic signal in Taft avenue – finance road intersection, (4) Installation of Rising Bollards, (5) Ensuring Safety of Pedestrians in Roadways (6) Changes in the Student's Health due to Sleep Deprivation.
Aside from the dream of becoming one of the best civil engineers of her era, she aims to be a successful businesswoman in the field of art, environmental, building design and construction whilst balancing the need of humanity with that of the environment. For questions and inquiries regarding this paper, she may be contacted through this information: 09568040977 / rosetem09@ymail.com

Esteven John B. Buduan is a graduate of Bachelor of Science in Civil Engineering from FEU-Institute of Technology in 2021. He dreams of being a world-renowned engineer and be involved in projects which will have great impact to society, especially to the less fortunate. Aside from being successful in the industry and being a master of his craft, he is also passionate in doing and promoting charity work, and volunteerism.

Airah Nicole O. Galang earned her degree of Bachelor of Science in Civil Engineering at FEU - Institute of Technology. She also ranked 3rd among the 87 graduates of Civil Engineering during the 2nd term of Academic Year 2020-2021. One of her ultimate dreams is to be a successful engineer both domestically and internationally, where she can also contribute to highlighting the talent of all Filipino Engineers. During her college years, she has co-authored several research papers: (1) Economic Viability Assessment of Rainwater Harvesting System for meeting Non-Potable Water Demand in Metro Manila, (2) ANGAT Dam Research, (3) Efficiency of Ferry System in Metro Manila, Philippines

Sofia Joy Galicia is a 5th year student of FEU-Institute of Technology taking up Bachelor of Science in Civil Engineering. She is passionate and dedicated. She believes that constant effort will turn to something great. Her goal for her career is to work abroad and contribute to the majestic infrastructures to the world.

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