Feasibility Analysis of Rainwater Harvesting System Implementation for Public Facilities in Palembang

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Abstract. Rainwater is one potential source of water that is often overlooked. Potential rainfall is often left discarded into runoff whereas with rainwater harvesting (RWH) system it could be harvested and used to meet the need for clean water and minimize the risk of flood by detaining the runoff. This study aims to analyze the feasibility of RWH systems implementation to meet the water need of public facilities in Palembang based on water balance concept. The behavioral model is used to simulate and mimic the RWH tank behavior. The analysis conducted on various scenarios based on RWH tank capacity and water demand. Two public facilities in the same area are analyzed, the office of Pengadilan Tinggi Agama (PTA) and SMAN 3 Palembang, along with 28 years of daily rainfall data. The financial analysis conducted using present worth analysis and payback period. For PTA, with 1050 L tank capacity, RWH is applicable and feasible. It can save the water up to 58% with an estimated payback period in 7.5 years. Nonetheless, although SMAN 3 has a bigger catchment area, because of the higher demand (21 times than PTA), RWH is not feasible to implement. The water saving efficiency is just 29% for a system with 4 tanks of 5100 L. These results are expected to be used as the initial analysis to find the typology of RWH systems implementation in Indonesia.

Keywords: Rainwater harvesting, behavioral model, tank, water saving efficiency, feasible

1 Introduction

Water is a renewable natural source that always will be needed for living, especially human being. Yet as the time goes by, water availability is no longer comparable towards water demand because of humans’ causes itself. Water Resources Institute (2017) predicted that in 2020 most of Asian countries will face water scarcity either in dry season or summer. As of this moment, Indonesians still use groundwater, which is discharged through water well– either dug, driven, or drilled–yet most of them are not legal according to the regulations that govern the groundwater usage. The erratically utilization of groundwater will only lead to some losses either in a short or long term. Furthermore, discharging
groundwater through water well which goes beyond the permitted capacity for daily use will damage the aquifer as the water is forcibly sucked causing a void that will also lead seawater intrusion into the area and alter the quality of the groundwater into a brine area. Hence, an eco-friendly water conservation system such as rainwater harvesting is needed in order to keep the environment safe. The area in which the quantity of rainfall is adequate to be conserved will be a potential place to install the system in order to fulfill the water demand. Rainwater harvesting (RWH) concept itself starts from collecting the rainwater from a catchment area then is accumulated and saved in a tank so that can be used as an alternative water source (Fewkes, 1999). Roof has been selected as a catchment area because it tends to be cleaner than other surfaces (Lee, 2012; Simmons, 2000). Moreover, RWH systems do not only provide benefits in the provision of clean water but indirectly also provide other benefits, such as reducing the roof runoff volume and financially provide cost savings from the use of rainwater (Zhang, 2009; Vivian, 2009). Similar studies corroborate that the rainwater harvesting system also provides an advantage from an economic standpoint (Nagaraj, 2011). The RWH system could be implemented both for domestic or public use.

The characteristic of the catchment area, potential rainfall, and water demand will contribute to the RWH system performance (Frasier, 1983). The most important part in the planning of RWH system is the storage tank capacity. Alteration in the catchment area and storage tank capacity will influence the system performance (Juliana, 2017). Tank sizing is the vital part of the system because if it is not at the optimum size, not only it will cost a lot but also the water saving efficiency is not efficient. Therefore, a comprehensive study on water saving efficiency should be conducted in order to analyze the feasibility of the RWH system implementation. This study aims to investigate the possibility of using RWH for public facilities such as office and school based on various tank capacity. A behavioral model which is one of tank sizing methods for RWH system planning consists of two algorithms, there are yield after spillage (YAS) and yield before spillage (YBS).

2 Method

In this study is a simple RWH system that used the roof as a catchment area are analyzed. Two public facilities are investigated in order to be able to compare the results albeit being public facilities yet are different from some aspects such as the catchment area, occupants, and also daily water demands. Daily rainfall data from last 28 years are used from two stations which are Sultan Mahmud Badaruddin Meteorological Station and Kenten Climatology Station from 1987 until 2014. Daily water demand for both public facilities are based on SNI (Indonesian National Standard) 19-6728.1.2002 for School, Office, and Workshop Place. For the water price usage is based on PDAM Tirta Musi Palembang regulation in 2011 which was authorized by the Mayor of Palembang..

The effective rainfall volume obtains by multiplying the rainfall with the catchment area and runoff coefficient.

\[ E_R = R_t \cdot A \cdot C \]  

(1)

Where \( E_R \) is the effective runoff (m\(^3\)), \( R_t \) is daily rainfall (mm), \( A \) is catchment area wide (m\(^2\)) and \( C \) is the ratio of the rainwater that could be caught in the catchment area.

The simulation of the RWH system is determined based on the water balance method.

\[ V_t = V_{t-1} + Q_t - D_t - E_t - L_t \]  

(2)

In this study, the effect of evaporation and losses is disregarded since the storage tank is below ground, so that :

\[ V_t = V_{t-1} + Q_t - D_t \]  

(3)
Where $0 \leq V_t \leq S$, and $V_t$ is storage volume at time $t$ (m$^3$), $V_{t-1}$ is the storage volume at time $t - 1$ (m$^3$), $Q_t$ is the volume that enters the storage in a time interval $t$ (m$^3$), $D_t$ is a demand release in lapse of time $t$ (m$^3$), $E_t$ is evaporation (mm), $L_t$ is the losses (mm) and $S$ is the storage capacity (m$^3$).

2.1 Behavioral Model

The behavioral model simulates the storage tank behavior based on its time variable through each algorithm (Fewkes, 1999). In a simple way, behavioral model only calculates the inflow and the outflow in accordance with the time sequence of the rainfall data. It can be either hourly, daily, or even monthly according to the data availability. There are two algorithms for the behavioral model, which are yield after spillage (YAS) and yield before spillage (YBS) (Jenkin et al, 1978; Mitchell, 2007). The RWH tank with behavioral modeling starts from inflow that comes from the rainfall, then it will be spilled if the tank is full (overflow). The remaining water in tank is yield based on demand. Figure 1 describes how the modeling steps are done.

Figure 1. RWH Tank Behavior

YAS describes that the yield is done after the spillage which is an overflow of the rainfall because it exceeds the capacity of the tank. The concept of YAS algorithm are:

$$Y_t = \min \left\{ \frac{D_t}{V_{t-1}} \right\}$$

(4)

$$V_t = \min \left\{ \frac{V_{t-1} + Q_t - Y_t}{S - V_t} \right\}$$

(5)

Figure 2 describes the steps of the storage tank behavior through the YAS algorithm method. As the rainfall flows into the tank, the excess water will be spilled as the overflow. Then the remaining water will be yield whether it is as much as the demand or the remaining volume of the tank itself.

Figure 2. YAS algorithm representation
Whereas the YBS algorithm stated that the yield is done before the spillage. In other words, after the inflow from the rainfall is done, the yield should be done first before the excess water is spilled into overflow (Figure 3).

\[
Y_t = \begin{cases} 
D_t \\
V_{t-1} + Q_t 
\end{cases} 
\]

(6)

\[
V_t = \min \left\{ V_{t-1} + Q_t Y_t \right\}
\]

(7)

As the rainfall flows into the tank, then yield is done directly even if the water volume exceeds the capacity of the tank. Then if the water volume is still excess then it becomes the overflow. Therefore, YBS algorithm sometimes called the overestimated simulation because the logic of yield before the spillage and the excess volume do not make sense.

The RWH system performance is evaluated with water saving efficiency. The water saving efficiency \( (E_T) \) is a percentage ratio between the yield and the demand of each various tank for each modeling algorithm. In this study, the tank stated as the optimum size if only the water saving efficiency is met nearly above half (50%) of the demand.

\[
E_T = \frac{\sum_{i=1}^{n} Y_t}{\sum_{i=1}^{n} D_t} \times 100
\]

(8)

2.2 Financial Analysis

As the water saving efficiency is modeled and analyzed, then each various tank system is estimated and analyzed from the financial aspects in order to find the optimum size of the tank. The RWH system cannot be stated as feasible and optimum if the system could save the water nearly 90% yet the capital cost of the system is so expensive. Therefore, the Present Worth Analysis (PWA) and Payback Period (PP) are used in order to see whether the system is feasible.

\[
NPV = AW \left( \frac{P}{A} \right) - PW
\]

(9)
The benefits of the system is the water savings equal to municipal water rate. Since each various tank size system is modeled and financially analyzed, then the optimum tank size is chosen from the criteria of water saving efficiency performance and also financial issues. The optimum size can be the smallest size, the biggest, or not even optimum and feasible due to no criteria is met.

3 Result and Discussion

3.1 Rainfall Data

The 28 years daily rainfall data from 1987 until 2014 is analyzed. Analysis conducted on 3 different conditions: the wet year, dry year, and 28 years. The year 2010 is chosen as the wet year with annual rainfall 3996,8 mm/year and 1987 as the dry year with only 1869,1 mm/year. Table 1 shows the rainfall type for 28 years data.

It is important to note that the ideal rainfall data time period is the daily rainfall data (Juliana, 2017). The average annual rainfall for the last 28 years from 1987 until 2014 in Palembang is 2809,9 mm/year and the maximum daily rainfall is 87,5 mm/day. This condition is categorized as a potential rainfall for RWH system implementation as the average annual rainfall is high and the maximum daily rainfall is categorized as heavy rain. The dry days and wet days percentage is also in a good ratio as the dry days are 34% and wet days are 64%.

| Rain type        | Rainfall          | % in 28 years |
|------------------|-------------------|---------------|
| No rain          | 0                 | 34,24 %       |
| Very light rain  | < 5 mm/hari       | 28,07 %       |
| Light rain       | 5 - 20 mm/day     | 25,21 %       |
| Medium rain      | 21 - 50 mm/day    | 10,74 %       |
| Heavy rain       | 51 - 100 mm/day   | 1,68 %        |
| Very heavy rain  | >> 100 mm/day     | 0,06 %        |

Figure 4 describes the movement line of the annual rainfall data and maximum daily rainfall.
Figure 4. Annual rainfall – maximum daily rainfall in Palembang

3.2 Catchment Area
SMAN 3 Palembang has 5 main buildings that can be used as the catchment area of the RWH system. Table 2 showing the area of each building.

| Building | Area (m²) |
|----------|-----------|
| A        | 495       |
| B        | 407       |
| C        | 275       |
| D        | 468       |
| E        | 309       |

Based on the shown table above, then three combinations for SMAN 3 Palembang are calculated to see which combination is the largest catchment area and can be used as the modeling data. The three combinations are:

1) B-A Buildings with 902 m² area
2) A-D Buildings with 770 m² area
3) C-F Buildings with 777 m² area

For SMAN 3 Palembang, as the B-A building has the biggest roof area, it has been chosen as a catchment area. Whilst for PTA, the rooftop area is 489 m². Figure 5 show the rooftop of each building.
3.3 Water Demand
The water demand for school and office according to SNI 19.6728.1.2002 is 10 L/person/day and for worship is 2 L/act. Assuming the Moslem students and employees are doing three times Salah then the water demand of each Moslem is 16 L/person/day and others is 10 L/person/day. Noting that this water demand is only for non-potable water needs. Table 3 shows the sum of water demand for each public facility.

Table 3. Water demand for each public facility

| Public Facility   | Students/ Employees | Religion   | Water Demand (liter/person/day) | Water Demand (m³/day) |
|-------------------|---------------------|------------|--------------------------------|----------------------|
| SMAN 3 Palembang  | 40 persons          | Non-Moslem | 10                             | 21,008               |
|                   | 1288 persons        | Moslem     | 16                             |                      |
| PTA               | No one              | Non-Moslem | 10                             | 0,976                |
|                   | 61 persons          | Moslem     | 16                             |                      |

3.4 Behavioural Model
The simulation of modeling is conducted on each public facility with three scenarios of rainfall data which are the wet year, dry year, and 28 years. For the PTA, the various tank size starts from 550 liter, 1050 L, 1550 L, 2000 L, 3100 L, 4100 L, 5100 L, and 8000 L. Figure 6 and 7 show the result of water saving efficiency for each tank size on the wet year, dry year, and 28 years. It can be seen from Figure 6 and 7 that water saving efficiency from various tank system may vary yet gradually increases.
From the analysis, the YBS algorithm tends to give the overestimate result than the YAS algorithm. It also can be seen that each $E_T$ displayed similar trends with regards to the influence of the
storage tank capacity. Furthermore, there is a positive gradient indicating that the increase in the storage tank capacity would lead to an increase in $E_T$. There is a difference between the $E_T$ in SMAN 3 Palembang and PTA. From Figure 6, it can be seen that for each particular year, the $E_T$ at SMAN 3 Palembang do not meet the minimum water demand (50%) even it’s used a very large storage tank capacity. Conversely, in PTA, the RWH system performance could meet the water need mainly in the wet year starting from 1050 L storage tank capacity. This was due to the ratio between demand and catchment area in SMAN 3 Palembang (0.023 m$^3$/m$^2$) is bigger than PTA Palembang (0.002 m$^3$/m$^2$). In other words, SMAN 3 has a higher demand (21 times than PTA). Although it has a bigger catchment area RWH is not feasible to implement at SMAN 3.

### 3.5 Financial Analysis

Using 11% as the annual interest and infinite period in PWA to make the break-even-point analysis and to see whether the system is feasible or not. Meanwhile, capital cost is a cost that each institution has to afford to implement the RWH system as the cost will vary depends on the tank size and the annual worth is the amount of money that is saved every year which should be spent for the water demand. In this study, it is considered that the building age is 10 years old so that the payback period must be under it. Table 4 and 5 to see the analysis of the PWA and PP in PTA.

#### Table 4. Financial analysis for SMAN 3 Palembang

| Tank Size (m$^3$) | Water Saving Efficiency (%) | PP |
|-------------------|----------------------------|----|
|                   | Wet year | 28 years | Dry year |
| 2000              | 6.72     | 5.16     | 4.47     | 9.5   |
| 3100              | 9.81     | 7.41     | 6.18     | 7.6   |
| 4100              | 12.33    | 9.21     | 7.49     | 7.1   |
| 5100              | 14.66    | 10.83    | 8.67     | 6.7   |
| 8000              | 20.22    | 14.65    | 11.43    | 7.5   |
| 3 x 5100          | 23.54    | 16.87    | 12.92    | 7.6   |
| 2 x 8000          | 29.17    | 20.49    | 15.61    | 8.9   |
| 4 x 5100          | 29.74    | 20.86    | 15.86    | 8.5   |
| 3 x 8000          | 32.52    | 22.65    | 16.86    | 10.7  |
| 5 x 5100          | 34.18    | 23.67    | 17.37    | 9.7   |
| 4 x 8000          | 34.77    | 24.01    | 17.49    | 12.8  |
| 5 x 8000          | 36.47    | 25.09    | 17.80    | 15.1  |

#### Table 5. Financial analysis for PTA Palembang

| Tank Size (L) | Water Saving Efficiency (%) | PP |
|---------------|----------------------------|----|
|               | Wet year | 28 years | Dry year |
| 520           | 39.81    | 31.54    | 28.29    | 12.3  |
| 1050          | 75.36    | 58.51    | 50.83    | 7.5   |
| 1550          | 85.17    | 68.90    | 61.26    | 7.9   |
| 2000          | 89.52    | 72.69    | 65.01    | 9.0   |
| 3100          | 94.94    | 77.68    | 69.66    | 11.2  |
| 4100          | 97.06    | 80.61    | 72.33    | 13.4  |
| 5100          | 98.26    | 82.76    | 74.33    | 14.9  |
| 8000          | 99.71    | 86.64    | 77.84    | 23.9  |
As seen from Table 5, in PTA, RWH system is only feasible from financial aspect for 1050 L, 1550 L, and 2000 L only. For SMAN 3 Palembang in Table 4, most of the tank size system is feasible starting from single 5100 liter until 4 tanks of 5100 liter.

4 Conclusion

From the analysis, it could be concluded that none of the facility can save the water fully 100%. For PTA, the optimum size of the tank for RWH System is 1550 liter because it can save the water up to 68.9% from 976 L daily water demand. It costs around Rp 6.201.500 with the payback period of annual worth from water saving is around 7 years and 5 months. Conversely, for SMAN 3 Palembang, there is no optimum and feasible size of the tank for RWH System. However, if the institution wants to implement RWH system, the system with 4 tanks of 5100 L can save water up to 32.5% from 21000 L daily water demand. This will cost around Rp 47.575.200 with the payback period of annual worth from water saving is around 8 years 8 months.

Albeit the catchment area of SMAN 3 Palembang is nearly twice of PTA, the water saving efficiency is literally only half of it. Also, the number of occupants of each facility is too much and the water demand difference is nearly 20000 L in a daily basis. Moreover, even though the wet/dry days ratio is quite potential, it is not the only one important variable in RWH System.

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**Acknowledgements**

This article’s publication is supported by the United States Agency for International Development (USAID) through the Sustainable Higher Education Research Alliance (SHERA) Program for Universitas Indonesia’s Scientific Modelling, Application, Research and Training for City-centered Innovation and Technology (SMART CITY) Project, grant #AID-497-A-1600004, Sub Grant #IIE00000078-UI-1.

This article is presented at the International Conference on Smart City Innovation 2018 that supported by the United States Agency for International Development (USAID) through the Sustainable Higher Education Research Alliance (SHERA) Program for Universitas Indonesia’s Scientific Modeling, Application, Research and Training for City-centered Innovation and Technology (SMART CITY) Project, Grant #AID-497-A-1600004, Sub Grant #IIE-00000078-UI-1.