Rainwater Harvesting System: Design Performances of Optimal Tank Size Using Simulation Software

Farisya Aliya Hilmi and Azianabiha A Halip Khalid

Abstract Rainwater harvesting (RWH) system has become a high potential source of water supply in urban areas. It is a practical solution to combat water crisis and can also contribute to reduce a storm's peak flow. This research aims to determine the feasibility and design performance of RWH for Kolej Melati, UiTM Shah Alam, Selangor. The performances of various storage tank sizes were calculated using Tanki NAHRIM 2.0. Finding from the software simulation was used to select the optimum tank size which provide highest water saving and reliability. The monthly analysis of the RWHS shows promising results of collectable water on the demand, in which the average reliability was higher than 50%. The result showed that the best tank size Kolej Melati is 100 m^3. About 46.6% of rainwater from roof can be used that provide 83.7% of water demand. This amount is equivalent to 2639.56 m^3 to fulfill the water requirement for 297 days per year. Therefore, the proposed implementation of RWH system in Kolej Melati is highly viable and the outcome could support green campus initiative by the university.

Keywords Rainwater harvesting · Optimum tank size · Tangki NAHRIM · Water saving efficiency

1 Introduction

Water availability is important for the health and productivity of the environment, ensuring the continuous supply of a variety of goods and services to support human well-being. Our earth is comprised of 71% covered in water which are mostly found in oceans and large water bodies. Water has been used by humans for various purposes either outdoor or indoor such as for drinking, watering garden and transportation. With such increasing in urbanization, water has been one of the highest demands and there is greater pressure to conserve existing water supplies [1]. According to

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Water World Council [2], the world population will rise by another 30–40% for the next fifty years and hence contribute to an increase of water demands which later will have significant outcome on the environment.

Malaysia is one of the countries that receive high rainfall in which the annual average rainfall for Peninsular Malaysia, Sabah and Sarawak are 2420 mm, 2630 mm and 3830 mm respectively. The high volume of rainwater in Malaysia has been taken as an alternative source to supply water by using rainwater harvesting system. However, the continuous growth of population and increasing in urbanization and industrialization have increase the demand of water. Therefore, in the planning and management of available water supplies, the principle of sustainability must be considered. In Sustainable Development Goal (SDG 6) has emphasizes the importance of conserving and handling water resources in a sustainable manner. The Malaysian government has taken many constructive steps to resolve the issue of water scarcity, including recycling and reuse of grey or waste water, increasing water tariffs, raising public awareness and encouraging the use of RWH system [3].

Besides, Malaysia has endured droughts and floods in various areas, so studying the feasibility of alternative water supplies in Malaysia to manage and preserve the sustainability of urban townships is important [4]. For the utilisation of rainwater as a water resource, the use of appropriate rainwater harvesting technology is significant. Rainwater harvesting system able to solve the issue of water shortage at the same time and minimise dependency on domestic water supply [5].

Rainwater Harvesting (RWH) system is a method to collect or store rainwater from roof as a catchment which later can be used as non-potable purpose such as landscape irrigation, toilet flushing and laundry [6]. It is also known as one of the sustainable methods as it emphasizes the using of natural resources. It can be used as potable usage but the microbial component needs to be reduced or removed with a proper treatment [7]. Even though it needs to be treated to satisfy legal requirements, rainwater has always been known to have considerable potential to add to the supply. This paper presents a study on the feasibility of RWH for Kolej Melati UiTM, Shah Alam and the design performance based on the optimum tank size by using Tangki NAHRIM 2.0.

2 Method

2.1 Sampling Location

UiTM campus Shah Alam was selected as the location of this study. A residential college of Block 4B of Kolej Melati (Fig. 1) was chosen to identify the optimum tank size. It is inevitable to develop RWH technology with one of its most important components, precipitation must be considered. A secondary data of hydrological data of rainfall was obtained from Drainage and Irrigation Department Malaysia (DID).

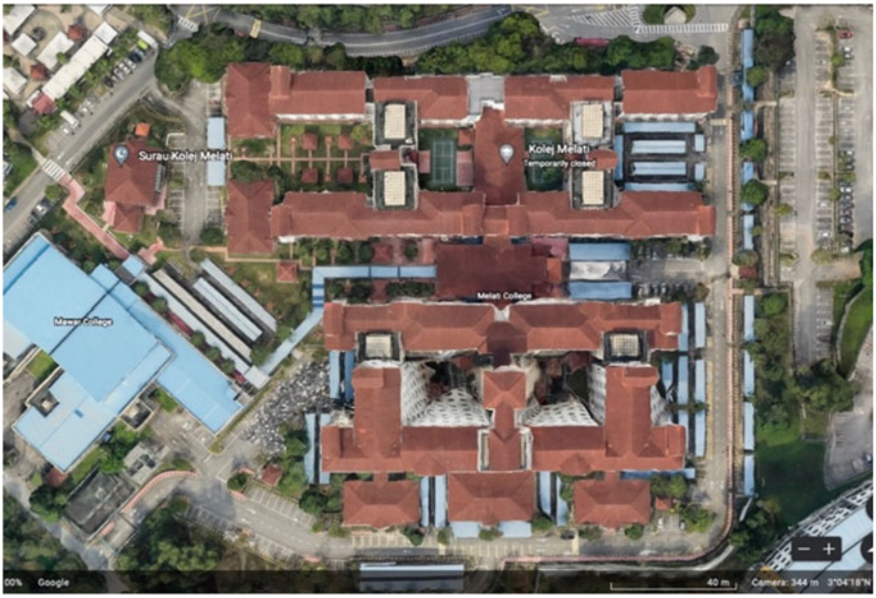

Fig. 1 Melati residential college, UiTM Shah Alam

The previous 15 years of rainfall data from the year 2003 to the year 2017 were used in the study.

2.2 *Tangki NAHRIM 2.0*

The latest Tangki NAHRIM 2.0 software was used to determine the optimum tank size for the selected location and to assess the viability of using rainwater tanks as a source of water addition. There are specific inputs such as rainfall data, roof information, water demand and the tank capacity needed to be filled in to get the optimum tank size for rainwater harvesting. The steps of the design are as the following:

2.2.1 Rainfall Data

To begin the analysis, UiTM Shah Alam rainfall station (Station No: 3014091) was selected. Table 1 shows the average annual and monthly rainfall. These rainfall data were used to analyse the potential of rainwater harvesting. Potential of rainwater harvesting can be calculated using the following equation [8]:

$$PRH = A_{RT} \times RC \times RI \quad (1)$$

Table 1 Average rainfall for station no: 3014091 per year and month

Year	Rainfall (mm)	Month	Rainfall (mm)
2003	1912.5	January	222.3
2004	2557.5	February	167.5
2005	1977.9	March	198.7
2006	3107.6	April	235.1
2007	2002.8	May	170.7
2008	3309.2	June	129.9
2009	2451.7	July	162.9
2010	2416.1	August	137.1
2011	2122.6	September	173.6
2012	2247.8	October	212.2
2013	1833.6	November	321.3
2014	2344.0	December	266.6
2015	2595.0		
2016	2319.6		
2017	2471.5		

Table 2 Runoff coefficient for roofing material [9]

Type of roof	Runoff coefficient
Galvanized iron sheet	>0.9
Tiles	0.8–0.9
Concrete	0.6–0.8

where, *PRH* is the potential rainwater harvesting (m^3), *A* is the area of the rooftop (m^2), *RC* is the runoff coefficient (−), and *RI* is the rainfall (m).

2.2.2 Roof Information

Block 4B Kolej Melati has approximately 1026 occupants. The roof measurements considered based on Google Earth were 104 m long and 31 m wide. Thus, resulting the catchment area to be about 3224 m^2. The rooftop runoff coefficient varies depending on the roof's material and slope as presented in Table 2. The building has runoff coefficient of 0.8 for concrete tiles material. First flush used was 1 mm as recommended by NAHRIM.

2.2.3 Water Demand

The required water demand for domestic use can be referred in guidelines provided by Urban Stormwater Management Manual (MSMA 2nd Edition) by Department of

Table 3 Rainwater consumption for domestic use [10]

Application	Average consumption	Average total rainwater demand
Toilet - Single flush - Dual flush	9 l/flush 6 or 3 l/flush	120 l/day 40 l/day
General cleaning	10–20 l/min	150 l/day
Sprinkler/ Handheld hose	10–20 l/min	1000 l/hour
Washing car	10–20 l/min	100–300 l/wash

Table 4 Water demand litres per day for block 4B Kolej Melati

Application	Unit	Average water used	Total water use (litres/day)
Single flush toilet with 9 l/flush	72 no	120 l/day	8640

Irrigation and Drainage (DID) as shown in Table 3. The toilet flushing was considered as the major non-potable used for the residential college. The total water demand is 8640 L/day. Therefore, the annual rainwater demand is 3153.6 m^3/year. The estimated water consumption was calculated in Table 4.

2.2.4 Tank Capacity

The maximum volume of water captured from the roof area to the rainwater harvesting system is used to construct the rainwater tank. The assumption on the tank size was based on previous research with almost similar amount of water demand. The smallest size to be about 10 m^3 and largest size 100 m^3 with an increment of 10 m^3 [11].

2.2.5 Reliability

Volumetric reliability is defined as the total volume of captured rainwater supplied divided by the total water demand and time reliability is the percentage of time when demand is fully met [12]. The following formula were used to determine the time and volumetric based reliability:

$$ReliabilityRatio = \frac{Deliverd\ Value}{Demand\ Value} \tag{2}$$

$$TR = 1 - \frac{df}{n} \times 100 \tag{3}$$

where *TR* is the time reliability, *df* is the number of failure days and *n* is the total number of days.

3 Result and Discussion

3.1 Feasibility of RWH Based on Hydrological Data

Before evaluating rainwater harvesting as a prospective source of water supply addition, it is critical to obtain and analyse rainfall data for at least the previous 10 years to obtain a good grasp of the rainfall pattern in a given location [13]. Precipitation data is required to calculate the volume of water that can be collected, considering rain depth and roof area, and then comparing that to the volume of demand needed. According to the rainfall data provided by Department of Irrigation and Drainage for year 2003 to 2017, the rainfall recorded are starting from January to December every year. From the data given, the pattern of the rainfall at station UiTM Shah Alam has be obtained.

The variation of historical data of annual rainfall for UiTM Shah Alam station is shown in (Fig. 2) where the mean annual rainfall is 2378 mm. The highest annual rainfall intensity recorded was in the year 2008, which is 3309.2 mm. The second highest rainfall is in 2006 with 3107.6 mm. Given the high seasonal variations, rainwater harvesting system will contribute to ensuring water supply for domestic and other needs [14]. All areas in Malaysia are subject to heavy rainfall with 80% a year which is between 2000 to 2500 mm of rain each year [15]. Hence, it is feasible for implementing RWH system as the intensity is more than 2000 mm. The result for the volume of the rainwater that can be harvest in a month using the Eq. (1)

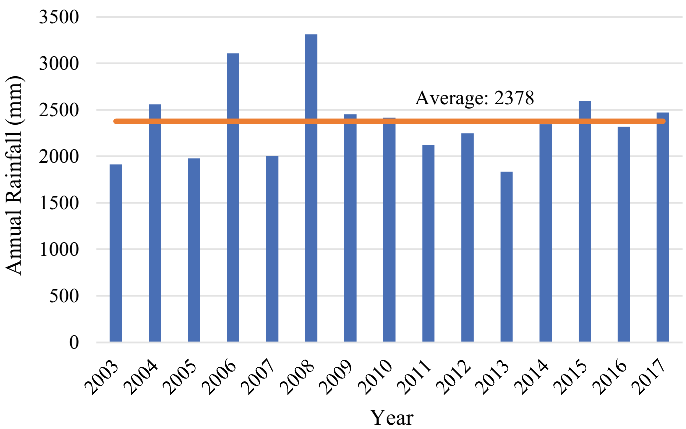

Fig. 2 Average annual rainfall for year 2003 to 2017 for UiTM Shah Alam station

Table 5 Potential of rainwater harvesting per month for catchment area of 3224 m^2

Month	Rainfall (m)	Coefficient	Catchment area (m^2)	Potential rainwater harvesting (m^3)
January	0.2223	0.8	3224	573.36
February	0.1475	0.8	3224	380.43
March	0.1987	0.8	3224	512.49
April	0.2351	0.8	3224	606.37
May	0.1707	0.8	3224	440.27
June	0.1299	0.8	3224	335.04
July	0.1629	0.8	3224	420.15
August	0.1371	0.8	3224	353.61
September	0.1736	0.8	3224	447.75
October	0.2122	0.8	3224	547.31
November	0.3213	0.8	3224	828.70
December	0.2666	0.8	3224	687.61

showed that November and December were the highest with 828.70 m^3 and 687.61 m^3 respectively (Table 5). This is because these months falls in northeast monsoon season.

When assessing the possibility of implementing rainwater harvesting systems, some factors such as local water demand, cost feasibility, and precipitation are considered to ensure the success of the system. The process for sizing a rainwater harvesting tank is based on historical rainfall data that may be used to estimate the amount of rainwater runoff gathered from the chosen roof [16]. Due to its location in the humid tropics, Malaysia has a high number of rainy days (138 to 181 days per year) thus the RWH system should be used to its full potential in order to save the most water in the reservoir that will be used during the dry season [8].

3.2 Design Performance Analysis

3.2.1 Water Saving and Storage

The storage and water saving efficiency for 8640 L per day of water demand for toilet flushing purpose is shown in Fig. 3. The water-saving and storage efficiency would grow with tank capacity for sizes ranging between 10 m^3 and 100 m^3 with the efficiency varied in the range from 35.9% to 83.7% and 19.9% to 46.6% respectively. Despite the small percentage variations, they resulted in water savings of several cubic meters each year and enhance the water supply network. In terms of cost, it was more cost effective to choose smaller tank considering economic purpose [13].

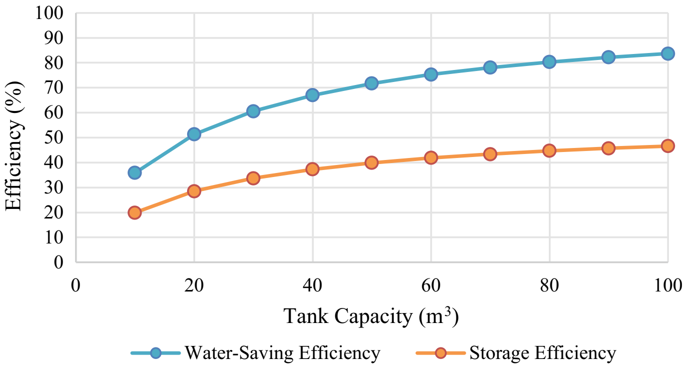

Fig. 3 Water saving and storage efficiency for tank size ranging from 10 m^3 to 100 m^3

Water saving efficiency is also known as volume reliability. It is calculated by referring on Eq. (2). The tank volumetric reliability (%) was used as a measure of the tank performance to assess the rainwater tank's water saving efficiency [17]. Based on water-saving efficiency curve, it shows that harvested rainwater can satisfied more than 80% of total water demand for tank capacity of 80 m^3 and larger. However, increasing the size of the tank by 10 m^3 for the given ranging capacity will only saves less than 5% of the total water consumption. A 50 m^3 storage capacity could provide 71.7% water demand which can save 1132.14 m^3 of water per year.

One of the key motivations for RWH is to save water, particularly in urban areas where fresh water is scarce [17]. Table 6 shows the volume of water that can be saved per year by implementing RWH system. It was found that for tank capacity of 20 m^3 and larger, it can provide more than half of the water demand which is 1576.80 m^3/year. Therefore, smaller tank capacity can be considered to be used as water saving efficiency is met nearly above half (50%) of the demand.

Table 6 Volume of water (m^3/year) that can be saved for different tank sizes

Tank capacity (m^3)	Water demand (m^3/year)	Water saving efficiency (%)	Water saved (m^3/year)
10	3153.6	35.9	1132.14
20	3153.6	51.3	1617.80
30	3153.6	60.6	1911.08
40	3153.6	67.0	2112.91
50	3153.6	71.7	2261.13
60	3153.6	75.3	2374.66
70	3153.6	78.1	2462.96
80	3153.6	80.3	2532.34
90	3153.6	82.2	2592.25
100	3153.6	83.7	2639.56

Storage efficiency curve is generally low compared to water saving efficiency curve. This is due to the amount of rainfall is quite high, so the low water demand causes spillage. It shows that almost half percent can be achieved if the tank capacity is 90 m^3 and above. To properly utilize the high amount of rainfall volume, the water demand must be increased to improve storage efficiency [13]. The tank size with reliability of more than 70% can be selected as optimum tank size [11]. Therefore, the tank capacity of 100 m^3 is chosen as an optimum size for Kolej Melati, UiTM Shah Alam. About 83.7% of water demand can be provided which equivalent to 2639.56 m^3 of water per year and 46.6% of rainwater from roof can be used.

3.2.2 Yield Spillage

A behavioural model was used to assess the effectiveness and performance of rainwater collection systems. This Tangki NAHRIM 2.0 software adopting a yield after spillage (YAS) model in which the concept is rainwater is collected until the storage is full. From the data provided, volume and time reliability can be analyse. Figures 4 and 5 show the volume and number of yield and spillage in each tank size for average annual and number of days. The reliability of the time is calculated using Eq. (3) and the result is tabulated in Table 7.

Based on Fig. 4, the volume of spill is higher than the volume of yield. However, the spill shows decreasing over the increasing of tank capacity while yield shows increasing in pattern. The YAS rule states that the yield is the lesser of the demand and supply [18]. From tank size 80 m^3 up to 100 m^3, the yield shows slightly consistent increase in which it matched with the water saving efficiency pattern. Whereas the spillage consistent with the trend storage efficiency. Thus, a larger tank should be provided so that the volume of spilled water can be minimized [19].

As shown in Fig. 5 is the time reliability. The pattern for yield and spill is contrast compared with (Fig. 4). The number of days rainwater yield satisfied the demand as

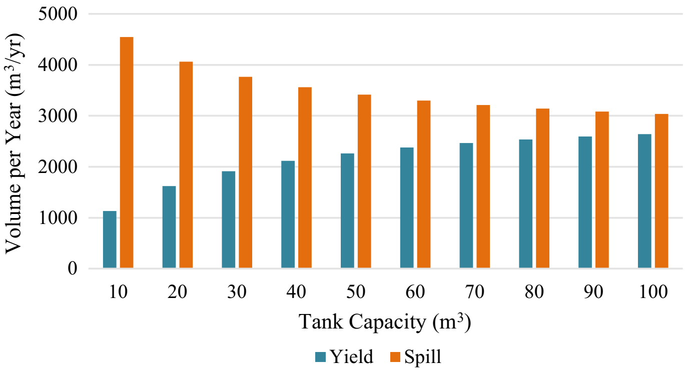

Fig. 4 Water saving and storage efficiency for tank size ranging from 10 m^3 to 100 m^3

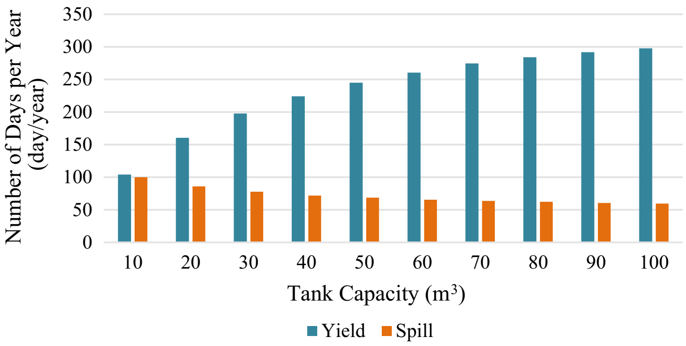

Fig. 5 Number of days yield and spillage in a year for each tank size

Table 7 Time reliability for water demand of 8640 L per day

Tank capacity (m^3)	Yield (day/year)	Time reliability (%)
10	104	28.5
20	160.5	44.0
30	197.9	54.2
40	224.1	61.4
50	244.9	67.1
60	260.6	71.4
70	274.7	75.3
80	284.1	77.8
90	291.7	79.9
100	297.9	81.6

tank size increases, roughly from 28.5% to 81.6% of days per year. On the other hand, the number of days per year for spillage decrease as tank size increases ranging from 99 to 59 days. For the tank capacity selected (100 m^3), the number of days rainwater yield fulfilled demand is 297 days per year which is about 81.6% and spillage occur at 59 days per year.

3.2.3 Percentage Tank Volume

Percentage tank volume is to determine the condition of water in tank based on number of days per year. It is divided into five classes which are the tank volume at 75% to 100%, 50% to 75%, 25% to 50%, less than 25%, and empty. The condition of water in tank within 15 years are illustrated in Fig. 6. From chart, the volume of water to full the tank increases as the tank size increase while the volume of water tank to empty decreases. The larger tank capacity will capture more rainwater and increase the period as it can store for a longer time compared with the small tank

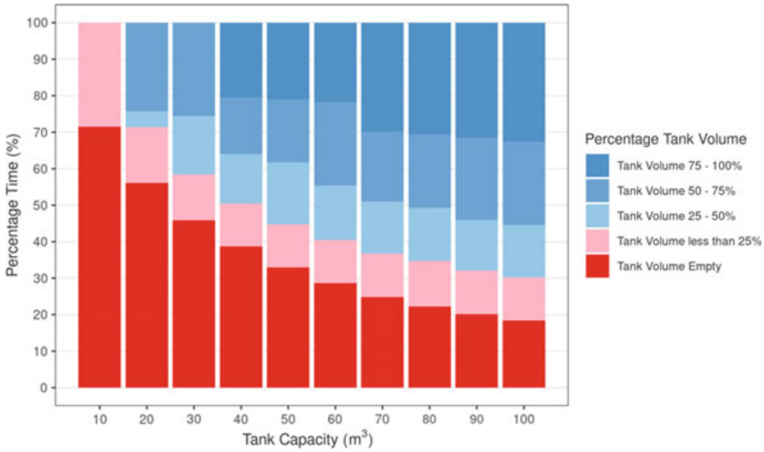

Fig. 6 Condition of water in tank within 15 years

capacity [13]. Furthermore, the smaller tank capacity will increase the spillage due to a large amount of rainwater enter the tank, hence, increase in the percentage time for tank volume to empty as it has higher water demand.

4 Conclusion

In conclusion, the rainfall data was chosen based on the nearest station from the study area which is UiTM Shah Alam station. The average annual rainfall is 2378 mm, thus, it is highly feasible for implementing rainwater harvesting system. The potential of rainwater that can be collected was identified based on the average monthly rainfall data. Next, a few inputs such as catchment area, roof information, water demand in litres per day and tank capacity were collected. From these, the optimum tank size for Block 4B Kolej Melati UiTM Shah Alam was determined. The tank size of 100 m^3 is selected as the optimum design. Based on this optimum size, about 46.6% of rainwater from roof can be used that provide 83.7% of water demand which equivalent to 2639.56 m^3 to fulfil the water requirement for 297 days per year. Most importantly, the system is expected to save water bill of approximately RM 4249.69 based on current tariff for government department.

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