Pertanika J. Sci. & Technol. 31 (6): 2961 - 2972 (2023)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Utilizing Rainwater Harvesting System for Water Scarcity at a Double-Story Residential House

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ABSTRACT

The use of rainwater is widely recognized as a dependable solution to reduce and mitigate the effects of water scarcity. Research on rainwater harvesting systems has increased significantly in recent years, especially on methods and treatment systems. A rainwater harvesting system can be described as collecting and storing rainwater that can be used rather than waste as runoff. A rainwater collection system might lessen the reliance on the public water supply. This study aims to determine the suitability of a rainwater harvesting system at a double-story house, thus identifying the suitable tank size for installation. This study's analysis used the Tangki NAHRIM 2.0 with localized input data such as rainfall, suitable roof area, and roof runoff coefficient. Findings from this study indicate that installing the rainwater harvesting system at a double-story house is suitable, and the optimum tank size is 3 m^3 by considering all the activities that contribute to water usage. Concisely, installing a rainwater harvesting system can reduce the monthly water bill and minimize the usage of treated water, thus preventing water scarcity in the future.

Keywords: Rainwater harvesting, residential building, runoff, water scarcity

ARTICLE INFO

Article history:
Received: 08 November 2022
Accepted: 14 March 2023
Published: 03 October 2023

DOI: https://doi.org/10.47836/pjst.31.6.18

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ISSN: 0128-7680
e-ISSN: 2231-8526

INTRODUCTION

Water security can be defined as the capability of a population to access the acceptable quality of water sufficiently. Nowadays, scarcity of freshwater has become a vital issue in sustainable development and has worsened in terms of its potential impact, thus leading to extreme global risk. The key factors contributing to the increasing demand for freshwater are the increasing global population, improving the standard of living, shifting the consumption pattern, and the increment of the irrigated agriculture area. Furthermore, the mismatch between demand and availability of freshwater is the principle of global water scarcity (Lani et al., 2018). The United Nations (UN) World Water Development Report (WWDR) in 2018 revealed that the availability of unpolluted, clean water and future opportunities had become a major issue as the global population reached 7.7 billion (UN Report, 2018).

However, the water system problem has worsened, and it is predicted that it will worsen by 2050 as the world population increases by 22 to 34%, from 9.4 to 10.2 billion people, due to the availability of local resources not in line with the population growth. For example, most of the rapid growth in the population is expected in developing countries (Africa and Asia) where the problem of potable water has already appeared (Boretti & Rosa, 2019). Several factors contribute to water shortages as a result of climate change, including changing weather (drought or floods), increasing pollution-producing activities, increasing human demands, and water consumption. The water scarcity issue should not be taken lightly because it can greatly impact a nation or even state and become a major concern worldwide, but little is known about how it has developed over time.

Malaysia is blessed with abundant annual rainfall, which will be wasted if not collected and recycled. Moreover, water collected from the rainfall can be used during water disruption; hence, this may reduce the water scarcity problem. Malaysia is heading towards a crisis due to increasing water demand, poor river basin management, and population growth. The problem can be prolonged when there is a shortage of treated water, irregular water demand, and suspension of investment in maintenance work such as repairs, improvements, or modifications to facilities and current water distribution (Rahman, 2014). The problem of water scarcity in Malaysia recently affected people across the nation, for example, the crucial water crisis in several states, especially Selangor, where it received the highest complaints about unscheduled water disruption. The analysis of the fundamental concept of water scarcity and water stress indicated the difficulties between population demands and excess use of resources to be met (Kummu et al., 2016). Thus, it is important to take precautionary plans such as improving water system management, finding a new alternative water source, and taking strict action on river pollution to reduce the possibilities of water scarcity.

Rainwater harvesting (RHW) can be an alternative source to reduce the water shortage problem. Water from RHW can be used for gardening, toilet flushing, and cleaning areas around the house, reducing water bills and saving more money. If the residents apply this method, it can reduce the water demand or water usage per day. Besides, by applying this method, the citizens supported the worldwide campaign known as the Sustainable Development Goal (SDG), which supports the sustainability of the water supply. RWH, also known as rainwater collection system, is a technology that collects and stores rainwater for human use. The rainfall can be fully utilized by collecting and storing rainwater rather than wasting it as surface runoff. The system can be as simple as rain barrels to complex structures with pumps, tanks, and purification systems.

The collected water can be used for watering gardens, washing cars and clothes, flushing toilets, and even being treated for human use (Struck, 2011). Generally, the RWH system is divided into surface runoff and rooftop. The advantages of implementing RWH are reducing the dependency on potable water and reducing floods in urban areas, thus reducing the nutrient loading to the river (Nguyen et al., 2018). RWH has many advantages in economy, technology, environment, and society. The benefits in terms of economics, through the implementation of the system, provided annual household cost savings of up to RM 240 per household as the installation of RWH was estimated to be cheaper compared to the higher water price (Lani et al., 2018). Moreover, it is well known that RWH could reduce peak water demand in urban water supply. The application of RWH in New South Wales, Australia, has indicated a significant result in the water savings from the main supply, even during the small rainfall intensity (Lani et al., 2018).

The benefits of reducing volume and peak demand can be interpreted as the smaller infrastructure size and savings in terms of operation and maintenance costs. It can be seen through the application of RWH in a suburb of Melbourne, where this application is able to reduce network pipe size and operating costs by up to 18% and 53%, respectively (Hajani & Rahman, 2014). Furthermore, implementing RWH can significantly lessen the operating costs and greenhouse discharge from the regional water supply systems (Lani et al., 2018). The application of RWH in Malaysia is suitable and just in time due to several water issues such as increased demand on water supply, high rainfall volume, and too dependable on surface water. In lieu of that, there is evidence that RWH can provide various socio-economic and environmental benefits, such as saving on utility bills, flow reduction during flash floods, and delaying the need to build new water supply facilities.

The implementation of RWH by the Malaysian government was implemented a long time ago, especially for public and government buildings. However, the overall success remains insufficient, mainly due to relatively higher investment, low water tariffs, lack of incentive from the government, low awareness among the public, and poor enforcement by the government. In reality, implementing RWH on a larger scale, such as in commercial buildings, can be more cost-effective compared to small-scale systems, such as residential areas, because the large roof area can provide sufficient volume for higher consumption in commercial buildings where higher water tariffs for commercial buildings than domestic tariffs. However, it is a good start to introduce the implementation of RWH in residential areas and educate the public on the advantages of the implementation of RWH. Thus, this study is developed to analyze the rainfall intensity in the targeted place to determine suitable RWH for a double-story residential house. The collected rainwater can be used for non-potable daily activities such as gardening and washing a car; thus, indirectly, the public can reduce the monthly water bill. It also can reduce and minimize water demand for daily use to reduce water scarcity in the future.

METHODOLOGY

Figure 1 indicates the study area, which focused on the location in Selangor due to frequent unscheduled water disruption. The application of the rainwater harvesting system for residential houses would be a great help during water disruption, and a double-story terrace house located at Jalan 3/12, Taman Seri Jaromas, 42600 Jenjarom, Selangor Darul Ehsan, has been selected to be as a reference and catchment area in order to do all the design work (Figure 2).

The data analysis used the Tangki NAHRIM 2.0, where the first Tangki NAHRIM was developed in 2008 using the visual basic and widely used in Malaysia to calculate and analyze optimal rainwater tank size (Lani et al., 2018). Tangki NAHRIM 2.0 (TN2) is developed based on established rainwater storage tank modeling methods, and the simulation model was developed in an R computing environment (R Core Team, 2013)

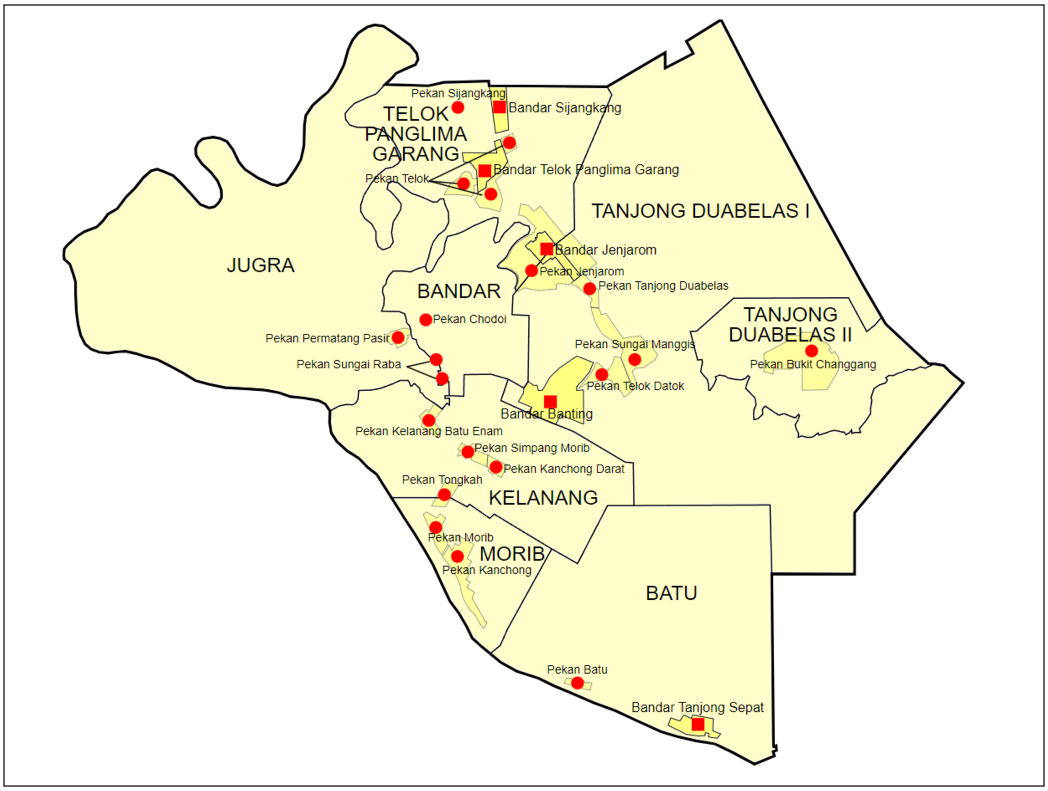

Figure 1. Map of Kuala Langat

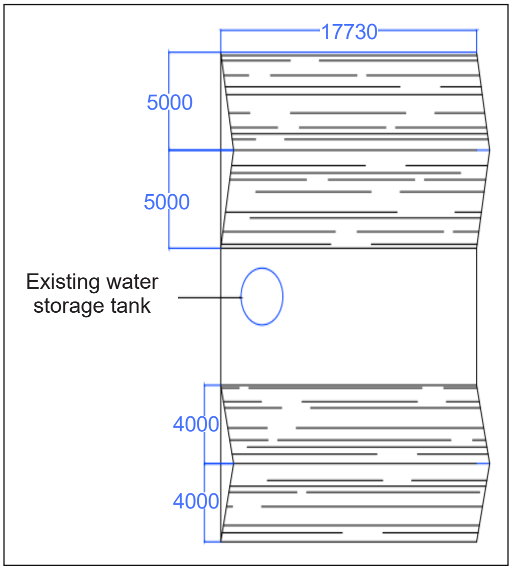

Figure 2. Catchment area

with the simplified web-based graphical user interface using the R Shiny framework (Chang et al., 2019). It also includes the built-in rainfall data for both Peninsular and East Malaysia, and the model inputs are rainfall data, harvestable roof area, roof runoff coefficient, first flush depth, water demand, and proposed tank capacity.

Input data related to rainfall data, such as Rain Day versus No Rain Day, Monthly Rainfall, and Annual Rainfall, are used as built-in rainfall data for station Sungai Manggis (station number 2815001), available from 1971 until 2017. The station was selected because it was identified as nearest to the site, Taman Sri Jaromas, Jenjarom, Selangor. The predetermined roof area, runoff coefficient, tank capacity, and water consumption from the tank selected to simulate the behavior of a rainwater tank. The runoff coefficient, which refers to the type of roof and the runoff coefficient, would be varied such as 0.50 for the thatched roof and 0.90 for the corrugated roof, but Liaw and Tsai (2004) suggested coefficients for all types of roofs 0.82, and for this study, we chose the average value as 0.8 and this similar with a study conducted by Goh and Ideris (2021).

TN2 adopts the yield-after-spill (YAS) water balance model from Jenkins et al. (1978) and Mitchell (2007) by assuming the RWH was utilized after spillage from the roof runoff inflow. The effectiveness of installing the RWH system can be assessed through a few parameters, such as the stored volume of rainwater in the storage tank, the efficiency of the tank, and average annual and monthly rainfall. It is important because the volume should be enough to be used for at least 2 days if water disruption happens, and this should be synchronized with average rainfall in that area; thus, a suitable storage tank can be provided. Next is the flow of water or discharge, which is the volume of water that moves toward a designated point over a specified period. This parameter should be the focus because the discharge of the water should be enough to carry all the water through the pipe and go to the outlet. The assessments of the parameters are the volume of water that can be stored (m^3), the efficiency of the water tank (%), and average annual and monthly rainfall (mm). Equations 1 and 2 indicate the formula volumetric water saving efficiency and efficiency of the water tank, respectively.

$$E_{ws} = \frac{\sum_{i=1}^{n} Y_i}{\sum_{i=1}^{n} D_i} \times 100 \quad (1)$$

n equals the total time interval in simulation, Y is the rainfall volume yielded for the water demand, D is the water demand for the rainwater harvesting system

$$E_s = \left[1 - \frac{\sum_{i=1}^{n} Qs_i}{\sum_{i=1}^{n} R_i}\right] \times 100 \quad (2)$$

R is the runoff volume, and Qs is the spillage or overflow.

RESULTS AND DISCUSSION

Rainfall Pattern

Rainfall collected around the area or basin is an important parameter that needs to be considered when determining how much water is available to support various demands such as agriculture, industry, irrigation, hydroelectric power production, and other human activities. The size or type of RWH relies on the rainfall pattern to forecast the frequency of rainfall. The forecasting uses the historical records of hydrological data and statistical analysis to increase the probability of extreme events such as floods, droughts, and severe storms that will occur in the future. The frequency or probability distribution can be used to relate the magnitude of such incidents to their frequency of recurrence. The monthly, seasonal, and yearly rainfall records are established by everyday rainfall collected at the individual stations, presented in the bulk of data concerning the rainfall climatology at any region or basin that has been stated (Nandargi & Mulye, 2012). Hence, it is very important to have an overview of the rainfall pattern for the respective study area to evaluate the suitability of installing the RWH. Figure 3 shows the comparison between rain days and no rain days from 1971 to 2017. The lowest number of rain days was recorded in 1983,

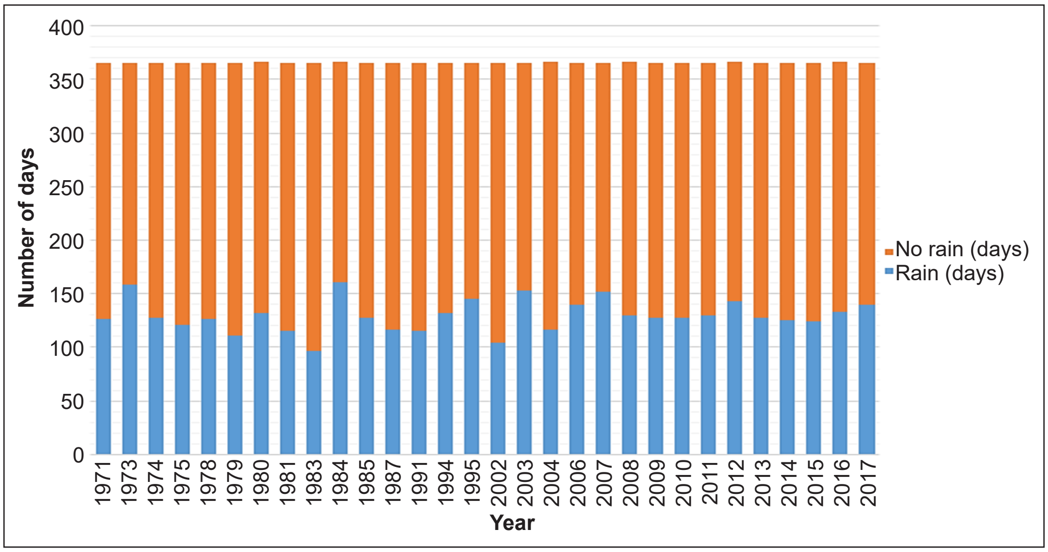

Figure 3. Average number of rain day versus no rain day for each year

with 97 days, while the highest number of rainy days ever recorded was 161 in 1984, and this data shows the potential of installing the RWH in that particular study area.

Meanwhile, Figure 4 depicts the monthly rainfall data from January to December 2017. It shows that the end of the quarter year, September to December, received the highest rainfall due to the location of Malaysia, either Peninsular or East, which has experienced a tropical climate influenced by the tropical airstreams, which have extreme heat and humidity, higher amounts of rainfall, and a climatic year centered on the northeast and southwest monsoons. The northeast monsoon (from November or December to March), the first inter-monsoon period (from March to April or May), the southwest monsoon (from May or June to September or early October), and the second inter-monsoon period are the four seasons of the climatic year (October to November).

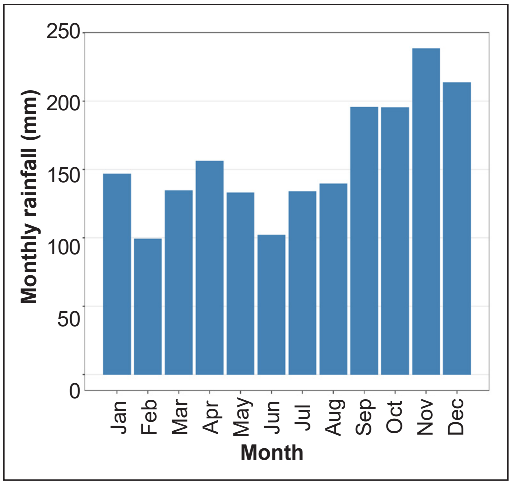

Figure 4. Monthly rainfall

The two monsoons' beginning and retreat are not well defined. Meanwhile, Figure 5 indicates annual rainfall at that particular station, and according to the JPS Sg Manggis or station number (2815001), however, there is no data recorded for

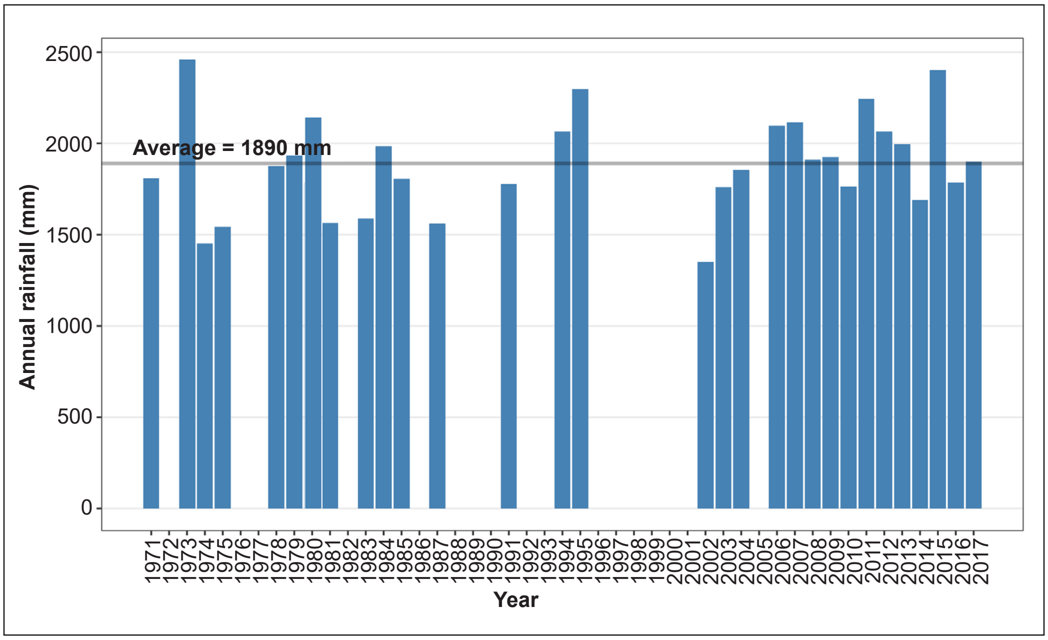

Figure 5. Annual rainfall

rainfall in the years 1976, 1977, 1982, 1986, 1988, 1989, 1990, 1992, 1993, 1996, 1997, 1998, 1999, 2000, 2001, and 2005 due to faulty of rain gauge and no rainfall during that time. Based on Figure 5, the average rainfall for 45 years of observation data was 1890 mm, and the lowest annual rainfall was in 2002, where the amount of rainfall was only 1350.3 mm per year, while the highest rainfall was in 1973, with the rainfall was 2455.2 mm per year.

The determination of the dependability of the water supply from the tank was based on the chosen parameters in which inflow, spillage, and outflow are calculated, which is crucial when working with discretized periods (Allen & Haarhoff, 2015). Therefore, it is required to channel the rainfall to the tank and concurrently withdraw the water needed to portray the rainwater tank accurately.

Optimum Sizing of Tank

The outputs generated using the TN2 were Percentage tank volume, Water-Saving, and Storage Efficiency, Yield versus Spillage by Volume, and Yield versus Spillage by Day, which later can be applied to determine the optimum size of the tank.

Percentage Tank Volume. The sizing of the tank can be determined through the percentage tank volume of rainfall captured from the roof area flow to the rainwater harvesting system. The optimum size of the tank increases when the annual rainfall at that particular area is less than 2000 mm, while it remains nearly constant for the higher rainfall area. The proposed size for the rainwater storage tank for this study was 3 m³ (256 L) according to the simulated result, as depicted in Figure 6. When the percentage of tank volume was 0% to 25%, the percentage of the time was 12.7%, and for 25% to 50%, the percentage of tank

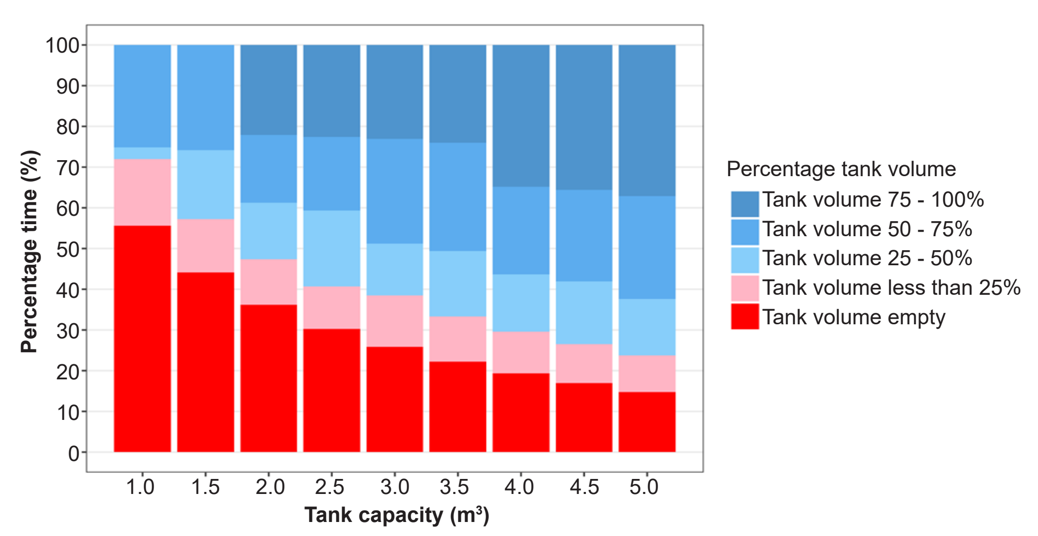

Figure 6. Percentages of tank volume

volume indicated the same percentage of time. Meanwhile, 50% to 75% of the tank volume obtained around 25.7% of the percentage time, and when the percentage volume of the tank reached 75% to 100%, it took 23% for the percentage of the time. In conclusion, the larger tank can store rainwater for a longer period compared to the smaller tank due to the small tank experiencing overflow when a larger volume of rainwater flows into the system.

Water-Saving and Storage Efficiency. Evaluation of the optimum size of the tank for the respective house was made according to the shape of water-saving and storage-efficiency curves. Figure 7 shows the shape of water-saving and storage-efficiency curves, and the results indicated a growth line between water-saving efficiency, storage efficiency, and tank capacity. When the water-saving and storage efficiency increased, the tank capacity also increased. Both efficiencies increase when the tank capacity is, at certain points, indicated by the marginal increase for the respective efficiencies (Daud et al., 2021; Goh & Ideris, 2021). For the proposed size tank capacity, which was 3 m^3, the water-saving efficiency was 77.3%, and the storage efficiency was 31%. This finding was slightly lower compared to the study conducted by Goh and Ideris (2021), which indicated that a tank sized 3 m^3 and above was able to obtain more than 90% water-saving efficiency and 38% storage efficiency fulfilled by the harvested rainwater.

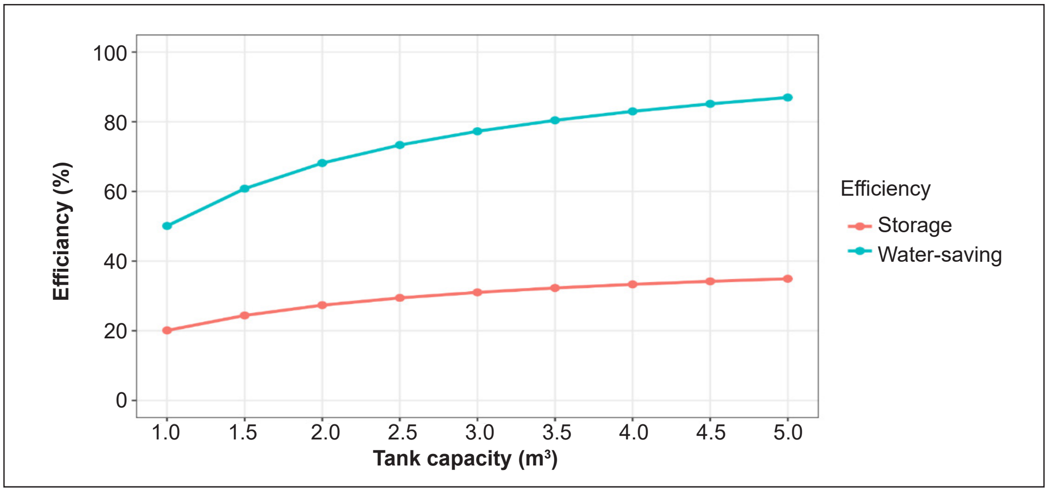

Figure 7. Water saving and storage efficiency

Yield Versus Spillage by Volume and Yield Versus Spillage by Day. TN2 implemented the yield principle after spillage, where the rainwater is added into the tank, and the spillage is immediately removed by limiting the tank volume (Khan et al., 2017). The data for yield versus spillage by volume for different tank capacities has been displayed in Figure 8. The result indicated contradictory results between the yield and the spill towards the tank capacity. When the tank capacity increased, the volume of yield increased as well;

however, as for spillage, the spill volume decreased when the tank capacity was increased. For tank size 3 m^3, the volume for yield was 128.4 m^3/year, and the volume for the spill was 285.6 m^3/year. A higher volume of spillage was reported compared to the volume of yield, and this was due to the rainfall pattern, as shown previously in Figure 5, which is influenced by the inter-monsoon seasons (Bakar et al., 2020).

Figure 9 shows the result of yield versus spillage by day against tank capacity. The number of days for spillage and the number of days for yield that are able to fulfill the demand was calculated and averaged by year. The result displayed that the spillage decreased, but at the same time, the yield increased when the tank capacity was bigger. Based on the proposed tank sizing, which is 3 m^3, the amount of spillage indicated 75.4 days per year; meanwhile, yield indicated 270.8 days per year. The capacity of the tank plays a big role because the capacity of the tank influences the water-saving efficiency and the volume of the water that can be stored. The 3 m^3 capacity of the tank has been proposed and is suitable for domestic usage because, from the obtained data, it can support the daily water demand for toilet flushing, general cleaning, and laundry. According to Campisano et al. (2017) and the Department of Statistics Malaysia (2014), around 5 toilet flushes per day per capita and 7 L per flush with an average of a resident of 4, the total water demand was around 140 L/day, and this can be up to 200 L/day when adding to the general cleaning and gardening (Goh & Ideris, 2021). Thus, installing this tank would reduce the usage of treated water and make the residence sustainable during the water disruption.

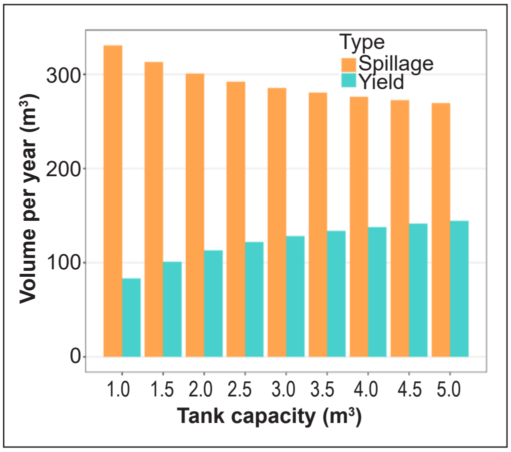

Figure 8. Yield versus spillage by volume

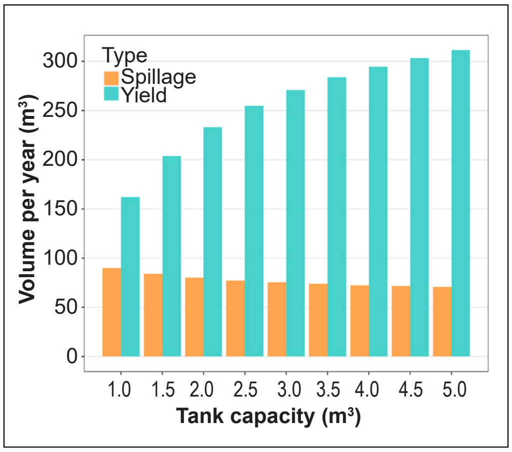

Figure 9. Yield versus spillage by day

CONCLUSION

Analysis of RWH using the TN2 can calculate the efficiency of a range of tank sizes based on several inputs to determine the optimal tank size. The utilization of RWH can be a good choice due to the abundant source of rainfall, thus reducing water scarcity in Malaysia. From the study, installing the RWH at a double-story house is suitable, and it can be concluded that water saving is also efficient when the tank sizes increase. Besides, the larger the size of tanks would be, the longer the period can store the rainwater. The optimum tank size for a double-story residential house is 3 m^3, considering all the activities that may contribute to water usage. Furthermore, to encourage the installation of RHW among residents in Malaysia, an awareness program on the advantages of using the RWH, such as being able to reduce the monthly water bill and good incentives from the government, can be implemented. Future studies on the application of rainwater harvesting among commercial and educational premises can be ventured.

ACKNOWLEDGEMENTS

The authors express their gratitude to those involved directly and indirectly in this study. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

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