


Relationship of Roof Areas and Rainwater Harvesting Tank Sizes for Squatter at Sion Village, Sarawak, Borneo Island

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Abstract

The rainwater harvesting system (RWHS) is widely recognized as a viable water source for drinking and non-drinking purposes, helping mitigate stormwater runoff. In 2019, an RWHS was installed in Sion village, a squatter that lacks connection to the potable water supply grid, with each household receiving a standardized tank size of 1.816 m³. However, the optimal tank size for rainwater harvesting can vary depending on roof sizes and water demands. Since the roofs in Sion village vary in size, this study aims to investigate the relationship between roof size and tank size, considering reliability percentage and installation cost. This investigation utilized the Tangki NAHRIM software and analyzed six different tank sizes: 0.682 m³, 1.136 m³, 1.589 m³, 1.816 m³, 2.270 m³, and 2.724 m³, across roof sizes of 60 m², 85 m², 100 m², 160 m², and 200 m². The study set a benchmark for reliability between 80% and 89%. The reliability percentage gradually improves with increasing roof and tank sizes, but the installation cost increases as well. A minimum tank size of 0.682 m³ was found sufficient to achieve a reliability of 85.02% for roof size of 85 m², 85.57% for 100 m², 88.84% for 160 m², and 90.07% for 200 m². Similar reliability percentage increment trends were observed for the tank sizes of 1.136 m³, 1.589 m³, 1.816 m³, 2.270 m³, and 2.724 m³. A tank size of 1.136 m³ provides a reliability percentage of 95.50% for a roof size of 60 m², making 1.136 m³ the minimum optimal tank size for this roof area. Results revealed that all the investigated roof sizes achieved higher reliability percentages than 85%, starting from the tank size of 1.136 m³. Moreover, the tank size of 2.724 m³ achieves a 100% reliability percentage for all roof sizes investigated except 60 m². The payback period for various tank sizes with different roof areas ranges

from 8.4 to 10.1 years against the water tariff charged by the Kuching Water Board (KWB). Thus, RWHS emerges as the most cost-effective alternative besides water mains for providing potable water supply to Sion village.

Keywords

Rainwater Harvesting System, Optimum Tank Size, Tangki NAHRIM, Payback Period, Reliability Percentage

1. Introduction

One of the most pressing concerns confronting developing countries is the provision of safe drinking water for both urban and rural residents, particularly those living in areas remote from natural surface water sources such as rivers and lakes. Other internal factors, such as rising population pressure and conflict, privatization, illegal settlement, changing tenure arrangements, poverty, socio-economic differentiation, and environmental degradation, also have an impact on the quality, accessibility, and dependability of water supplies. In Malaysia, some rural areas are not connected to the potable water supply grid. The water source is mainly from the nearby river, which is of poor quality, especially in the areas exposed to logging activities. Malaysia's river water is usually polluted or contaminated, resulting in many waterborne diseases [1]. Other developing countries also usually face this problem [2] [3].

The Sarawak government has made numerous efforts to provide a clean drinking water supply. The main water suppliers in Sarawak are the Kuching Water Board (KWB), Sibu Water Board (SWB), Northern Region Water Board (NRWB), and the Sarawak Rural Water Supply Department (JBALB) [4]-[6]. The function of JBALB is to supply hygienic water to the rural residents, and their goal is to ensure 100% coverage for all rural residents by the year 2025 under the Sarawak Alternative Water Supply (SAWAS) programme [7]. SAWAS focuses on building centralized water treatment plants for larger rural communities through the ultrafiltration and reverse osmosis water treatment process. The state's current clean water supply coverage is only 81.4% [8]. Although the Malaysia Federal and Sarawak State governments allocate funding to the SAWAS, more is needed to achieve the goal of 100% clean water supply coverage throughout the state by 2025. The cost of setting up a water treatment system can be substantially high, as it includes the cost of constructing the entire water treatment facilities and connecting them to a water distribution network.

Hence, JBLAB needs to take a different approach under the SAWAS initiative. As Sarawak is blessed with abundant rainfall, one of the ways to ensure a reliable and sustainable raw water supply to the rural community for inland areas is to install a rainwater harvesting system (RWHS) for each rural household. Rainwater can be used for potable and non-potable purposes and can also be stored as a

backup supply in times of water scarcity [9]. This approach could assist SAWAS in achieving 100% clean water supply coverage throughout Sarawak.

For 4000 years ago, the RWHS has been introducing and delivering high-quality water for drinking and cooking [10]. In Malaysia, the National Hydraulic Research Institute Malaysia (NAHRIM) is actively involved in designing and installing RWHS [11]. The water pH collected in rural areas is around 6 [12] [13]. A typical RWHS is known to have 80% to 89% efficiency in capturing rainwater [14] [15]. The factors affecting the reliability of RWHS are water demand, rainfall intensity, roof size, and rainwater harvesting tank size. The rain harvesting tank should be large enough to store sufficient captured rainwater to attain a higher efficiency or reliability percentage of the water supply. Other factors affecting the optimum rain harvesting tank size are climate, population, and environment.

In this study, the selected study area is Sion village, a squatter located in the Serian Division, Sarawak. There is no water supply at Sion village. Global Peace Foundation Malaysia installed the RWHS for Sion village under the Communities Unite for Purewater (CUP) programme in 2018 to provide a clean water supply to the Sion community [16] [17]. The standard tank size installed was 2 m³ for each household, without considering the roof sizes and water demands. However, the optimal rainwater harvesting tank size can vary depending on the roof size and water demands. Each house in this study had a distinct roof size and water demand. Therefore, this study's novelty focuses especially on the analysis and design of optimal RWHS tank size and its relationship with roof sizes for a squatter settlement located in the tropical region.

2. Study Area

The selected study area is Sion village, located in Tapah area, Serian Division, Sarawak, Malaysia. Sion village is located east of Beratok village [18] [19] and 3 km northeast of Tapah, about 21 Miles south of Kuching city, Sarawak (refer to **Figure 1**). The settlement is made up of a variety of oddly shaped wood and brick dwellings that the villagers constructed using whatever resources they could find or afford. The gravel road towards Sion village is full of potholes and flooding in certain areas.

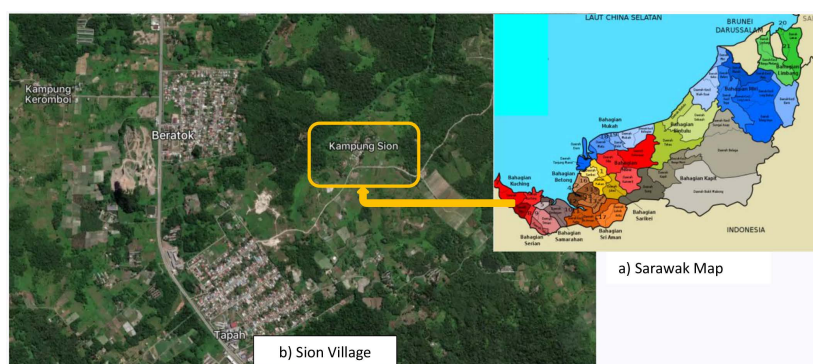


Figure 1. Locality of Sion Village.

Sion villagers place less emphasis on children's education since children are considered the family's primary labor force. The village's ladies will often stay at home, take care of the household chores, and grow vegetables for the family's consumption. There are 42 households in total, with approximately 200 villagers. Most villagers are Ibans and Bidayuh, with a small percentage of mixed-parentage Chinese and Malay [20]. Most villagers work as laborers in Kuching, with fewer working in small-scale farming.

In the past, the Sion communities mainly relied on rainwater and a river located 300m away as their primary water source [16]. In recent years, the nearby river water has been severely polluted by the upstream pig and poultry farms, making it unsuitable for potable usage. Villagers began to get rashes that turned into open sores and scabs due to taking baths in the polluted river. Realizing this, Sion villagers turned to rainwater as their primary water source. Due to financial restrictions, the rainwater was collected using modified zinc pieces as a gutter, and the harvested rainwater was stored in buckets, jars, barrels, and tanks. During the drought season, some Sion villagers walk 3km daily to the market nearby to purchase drinking water, even though their average household income is only RM800 per month.

Starting in 2018, Sion villagers have improved access to clean water under the Communities Unite for Purewater (CUP) programme, initiated by Global Peace Foundation Malaysia. YTL Power sponsored this CUP project for the Social Outcome Fund in partnership with Agensi Inovasi Malaysia (AIM). CUP aims to uplift the welfare of rural and impoverished communities by providing clean water. To date, CUP has benefited over 4256 people in 21 communities across Malaysia through technical solutions that improve access to water, a filtration technology that provides clean drinking water, and provides Water, Sanitation, and Hygiene (WASH) training that increases knowledge and awareness on water management and hygiene. This project was started in February 2018 and was completed in February 2019.



Figure 2. RWHS designed by the team from Swinburne Sarawak in 2019.

Each house that participated in the CUP programme received a water tank (as presented in **Figure 2**), water purifier, properly installed gutters, and plumbing to collect rainwater from the rooftops effectively. Using the Global Peace water purifier gives each family access to clean water for all of their household needs. In addition, a high-volume LifeStraw Community filter was also installed to provide villagers with free access to clean water (refer to **Figure 3**). This filter has the ability to remove up to 99.9999% of bacteria, viruses, and sediments from the water, making it safe to drink even without boiling [21].



Figure 3. LifeStraw rainwater filter system.

3. Methodology

In this study, Tangki NAHRIM, a rain harvesting design tool, is utilized to find the optimal tank size [22]. This software can be downloaded for free from the official website of National Water Research Institute of Malaysia (NAHRIM). Tangki NAHRIM considers rainfall volume and pattern, roof catchment area, and water demand. Input data include daily rainfall, roof area, percentage of losses from roof runoff, daily water demand, and tank volume. The output includes total rainwater captured, daily rainwater volume delivered, system reliability, rainwater utilization percentage, storage efficiency, and the number of days without rain or with an empty tank. Manual calculations will be used to verify the software's reliability.

Four main parameters to determine the most appropriate and optimum size of a rainwater harvesting tank: rainfall pattern, household size, catchment area, and water demand. The potential impacts of each parameter are discussed as follows:

Rainfall pattern: The rainfall pattern is essential to analyze the availability of rainwater to be stored in the rainwater harvesting storage tank for household water supply. Historical daily rainfall data for Tarat Rainfall Station from 2013 to 2023 were obtained from the Department of Irrigation & Drainage (DID) Sarawak. The rainfall data was input into TANGKI NAHRIM rainwater harvesting simulation software to determine the reliability percentage.

Household size: Household size is crucial to determine the total water demand and consumption. The quantitative survey showed that the average household size in Sion village is six persons.

Catchment area: The roof catchment area is the horizontal roof plane under the eaves. The 42 households in Sion village were grouped into five roof sizes, namely 60 m², 85 m², 100 m², 160 m², and 200 m². Roof runoff flow into RWHS is calculated using Equation (1).

$$Q = I_{\text{eff}} \times C \times A \quad (1)$$

where Q is the daily runoff (L), C is the runoff coefficient, A is the roof area connected to the tank (m²), and I_{eff} is the daily effective rainfall (mm). I_{eff} is obtained using Equation (2).

$$I_{\text{eff}} = \text{Daily rainfall} - \text{First flush} \quad (2)$$

First flush is essential to remove dust, bird and animal droppings, leaves, and debris from the roof surface.

Water demand volume: Questionnaires as shown in the appendix, were used to collect local water usage data. The details of the water demand in Sion village are presented in **Table 1**.

Table 1. Daily water demands per person in rural areas [8].

Activities	Water Demand (L)
Drinking	4
Cooking	6
Personal hygiene	50
Laundry	20
Utensils Washing	10
House Cleaning	15
Toilet	35

Figure 4 presents the detailed steps in modeling a rainwater harvesting tank to determine the relationship among water demand, roof sizes, and optimum size of the rain harvesting tank using Tangki NAHRIM software. The standard procedures for optimizing rain harvesting tank are:

a) Insert rainfall data—Kuching rainfall data is not available in the Tangki NAHRIM rainfall station dropdown menu. Hence, rainfall data for the Kuching station will be added manually and loaded into Tangki NAHRIM software.

b) Input roof information—roof information, including size and runoff coefficient for roof material, is input into Tangki NAHRIM. The runoff coefficient for a zinc roof that installed in this study is 0.95 [23].

c) Input water demand information—the water demand per day for each household is required to determine the optimum tank size for each household.

d) Input first flush volume—first flush is essential for protecting the rainwater quality by isolating the contaminant-laden water, including organic and inorganic fine particles from the roof. The first flush volumes required for different roof

areas are tabulated in **Table 2**.

e) Run the simulation—The final step is running the simulation, and the resulting output will present the reliability of different rainwater harvesting tank sizes.

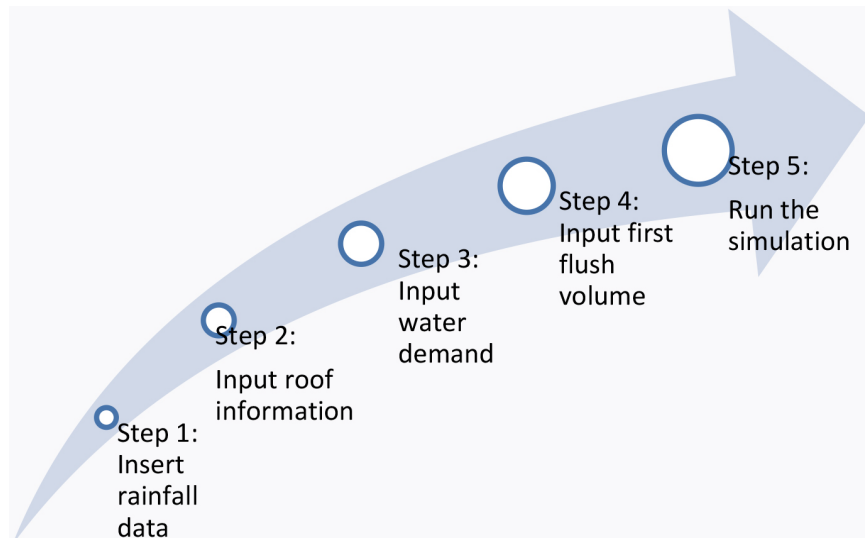


Figure 4. Chronology of the design process.

Table 2. First flush requirement [23].

Roof Area (m ²)	First Flush Volume (m ³)
Less than 100	0.025 - 0.05
100 - 4356	0.05 - 2.5
Greater than 4356	2.5

To investigate the relationships among water demand, roof sizes, and optimum rain harvesting tank size for rural areas in the tropical region, various graphs will be plotted. The optimum tank size will be justified according to the reliability percentage. Higher reliability indicates that the rainwater harvesting system (RWHS) can store sufficient water to meet the water demand. The developed graphs that will be used to determine the optimum tank size for rural areas in the tropical region, particularly in Borneo, are:

- Reliability Percentage vs. Roof Area
- Tank Size vs. Roof Area
- Installation Cost vs. Tank Size
- Reliability Percentage vs. Installation Cost of Various Tank and Roof Sizes

According to the World Health Organization (WHO), the Drinking-Water Quality: Small Water Supplies guideline explicitly aims for 100% reliability in small or rural systems is often impractical [24]. However, reliability beyond 90% often requires exponentially greater infrastructure investment, such as larger roofs, tanks and backup systems. Therefore, the targeting reliability for RWHS ranges from 80% - 89% to achieve adequate potable capacity at reasonable cost [25]-[27].

Thereafter, a cost analysis will be conducted to determine the payback period for the optimum tank size. RWHS installation costs as a whole are regarded as an early investment. After that, the rainwater collected will be supplied continuously without any charge. By comparing the RWHS installation cost against the water tariff charged by Kuching Water Board (KWB), a payback period analysis will be carried out to calculate the return on investment (ROI) for installing the rainwater harvesting system (RWHS).

4. Results and Discussion

4.1. Roof Sizes and the Reliability Percentage for Different Tank Sizes

Figure 5 presents the relationship between the roof sizes and the reliability percentage for different tank sizes. Six different tank sizes are investigated, including 0.682 m³, 1.136 m³, 1.589 m³, 1.816 m³, 2.27 m³, and 2.724 m³, obtained from the WEIDA Polystor HDPE Water Tank Catalogue. Meanwhile, the Sion village's unstandardized existing roof sizes were grouped into 60 m², 85 m², 100 m², 160 m², and 200 m². The performance of these different tank and roof sizes was measured using reliability percentage. Generally, smaller tank sizes will achieve a lower reliability percentage, while bigger tank sizes will obtain a higher reliability percentage. The ideal reliability percentage to achieve is 100%.

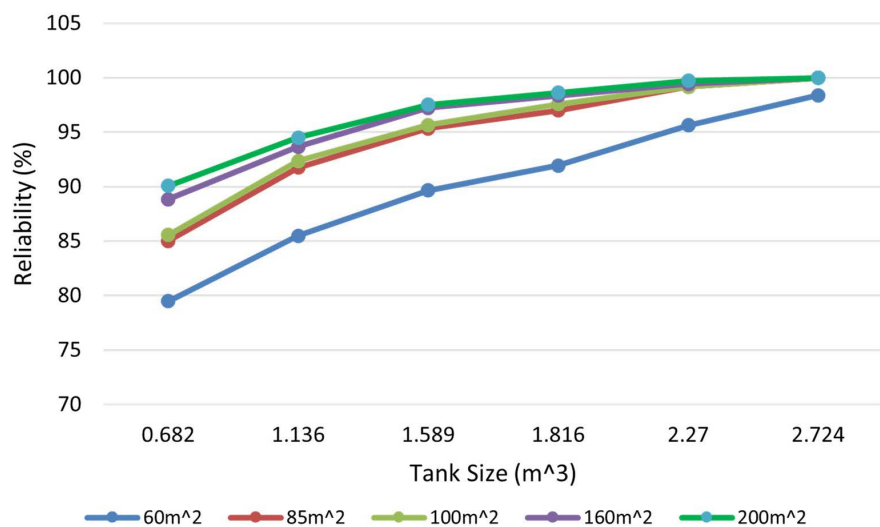


Figure 5. Reliability percentage vs roof area graph.

In this study, the supply of harvested rainwater is calculated according to yield-before-spillage (YBS) algorithm. YBS algorithm is adopting an optimistic approach, where the water is expected to be drawn from the storage tank and supplied to the end users before overflowing the tank. The remaining water after usage will be stored in the tank for use in the following days [28]. Since a higher reliability percentage will raise the cost of installing rainwater collecting tanks, it is unnecessary to attain a 100% reliability percentage for the ideal tank size. **Figure**

5 demonstrates that the tank size of 2.724 m³ achieves a 100% reliability percentage for any roof size except for the roof size of 60 m². However, the tank size of 2.724 m³ is much more expensive than other smaller tanks. Therefore, installing 2.724 m³ of rainwater harvesting for each household in Sion village is not financially feasible.

Therefore, a more practical rain harvesting tank size should be chosen for Sion village. Results revealed that the smallest tank size of 0.682 m³ with the smallest roof size of 60 m² could achieve a 79.49% reliability percentage. The reliability percentage is improving gradually as the roof sizes increase from 60 m² to 200 m², with 85.02% for 85 m², 85.68% for 100 m², 88.85% for 160 m², and 90.07% for 200 m². Similar reliability percentage increment trends were observed for tank sizes of 1.136 m³, 1.589 m³, 1.816 m³, 2.270 m³, and 2.724 m³.

The reliability percentage for the tank size of 0.682 m³ and the roof size of 60 m² is 79.49%. With the same roof area, it was observed that the reliability percentage increased significantly for the tank size of 1.1368 m³ to 95.50%. The results show that from tank sizes of 1.136 m³ to 2.724 m³, the reliability percentages for the roof area of 60 m² are increasing gradually until yielding 98.39% for the tank size of 2.724 m³ (refer to **Figure 5**). The results of the roof area of 85 m², 100 m², 160 m², and 200 m² revealed that all the investigated roof sizes achieved higher reliability percentages than 85%, starting from the tank size of 1.136 m³, meeting the benchmark for reliability percentage between 80% and 89%. The findings clearly demonstrated that increasing roof area and tank sizes would raise reliability percentages, leading to increased efficacy in rainwater collection to provide for the village's water needs. Considering the available tank sizes with the corresponding reliability percentage against various roof sizes, the minimum tank size of 1.136 m³ accomplishes a reliability percentage of more than 85% at Sion village for the roof size of 60 m². While for other roof sizes, including 85 m², 100 m², 160 m², and 200 m², a minimum tank size of 0.682 m³ is adequate to gain a reliability percentage greater than 85%.

4.2. Relationship between Tank and Roof Sizes to Achieve the Reliability Percentage

Figure 6 demonstrates the relationship between the tank and roof sizes to achieve a reliability percentage of 75%, 80%, 85%, 90%, and 95%. It was observed that for a roof size of 60 m², a reliability percentage of 75% can be achieved with a tank size of 0.52 m³. While roof areas of 85 m², 100 m², 160 m², and 200 m², can attain reliability percentages of 75% with tanks that are in the size of 0.34 m³, 0.33 m³, 0.30 m³, and 0.30 m³, respectively. A reliability percentage of 80% can be achieved for roof sizes of 60 m², 85 m², 100 m², 160 m² and 200 m², with the tank that is 0.74 m³, 0.50 m³, 0.40 m³, 0.33 m³, and 0.33 m³ in size, respectively. Meanwhile, roof sizes of 60 m², 85 m², 100 m², 160 m², and 200 m² are able to achieve 85% reliability percentage with the corresponding tank sizes of 1.07 m³, 0.67 m³, 0.65 m³, 0.59 m³ and 0.50 m³, respectively. With roof sizes of 60 m², 85 m², 100 m², 160 m², and 200 m², correspondingly, tank sizes of 1.61 m³, 0.97 m³, 0.97 m³, 0.90 m³, and 0.70 m³

can achieve 90% reliability rate. With tanks that are 2.20 m³, 1.60 m³, 1.40 m³, 1.28 m³, and 1.20 m³ in sizes, and corresponding roof sizes of 60 m², 85 m², 100 m², 160 m², and 200 m², can yield a reliability percentage of 95%. Generally, the findings illustrated that the roof and tank sizes are proportional with reliability percentage. Bigger tank sizes with larger roof areas will yield a higher reliability percentage, while smaller tank sizes with smaller roof sizes will lead to low reliability.

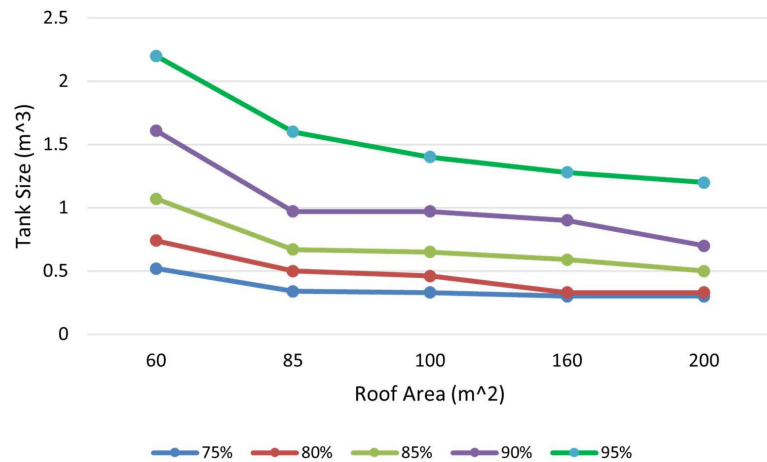


Figure 6. Tank size vs. roof area graph.

4.3. Cost Analysis

RWHS costs include the materials and installation of the WEIDA Polystor HDPE water tank, gutter, water rundown pipe, etc. Generally, the polystor tank's price is proportional to the tank size. Table 3 presents the installation cost and payback period for different tank and roof sizes at Sion village. As the desired reliability percentage is 80% to 89%, the minimum tank size achieved 80% volumetric reliability is indicated in yellow. The payback period is the time required to get the equivalent return from the investment of constructing the RWHS system, calculated based on Equation (3).

$$\text{Payback period} = \frac{\text{Total Cost of RWHS installation}}{\text{cost of water saved}} \quad (3)$$

where the cost of water saved is defined as the total volume of water supplied by RWHS X the water rate charged by Kuching Water Board (KWB).

Table 3. Cost analysis for different roof areas.

Roof size (m ²)	Tank Size (m ³)	Rainwater yield (L)	Reliability (%)	Price saving (RM)	Installation cost (RM)	Payback Period (Years)
60	0.682	92.85	79.49	90.00	729.03	8.1
	1.136	99.86	85.50	97.00	976.53	10.1
	1.589	104.74	89.67	102.00	1261.53	12.4
	1.816	107.37	91.93	104.00	1336.53	12.8
	2.270	111.71	95.64	108.00	1591.53	14.7
	2.724	114.92	98.39	111.00	1861.53	16.7

Continued

85	0.682	99.3	85.02	96.00	812.46	8.4
	1.136	107.17	91.76	104.00	1059.96	10.2
	1.589	111.37	95.35	108.00	1344.96	12.5
	1.816	113.29	96.99	110.00	1419.96	12.9
	2.270	115.84	99.18	112.00	1674.96	14.9
	2.724	116.8	100.00	113.00	1944.96	17.2
100	0.682	99.95	85.57	97.00	831.00	8.6
	1.136	107.88	92.36	105.00	1078.50	10.3
	1.589	111.72	95.65	108.00	1363.50	12.6
	1.816	113.96	97.57	111.00	1438.50	13.0
	2.270	115.84	99.18	112.00	1693.50	15.1
	2.724	116.8	100.00	113.00	1963.50	17.3
160	0.682	103.77	88.84	101.00	960.78	9.5
	1.136	109.41	93.67	106.00	1208.28	11.4
	1.589	113.57	97.23	110.00	1493.28	13.6
	1.816	114.88	98.36	111.00	1568.28	14.1
	2.270	116.16	99.45	113.00	1823.28	16.2
	2.724	116.8	100.00	113.00	2093.28	18.5
200	0.682	105.2	90.07	102.00	1034.94	10.1
	1.136	110.4	94.52	107.00	1282.44	12.0
	1.589	113.92	97.53	111.00	1567.44	14.2
	1.816	115.2	98.63	112.00	1642.44	14.7
	2.270	116.48	99.73	113.00	1897.44	16.8
	2.724	116.8	100.00	113.00	2167.44	19.1

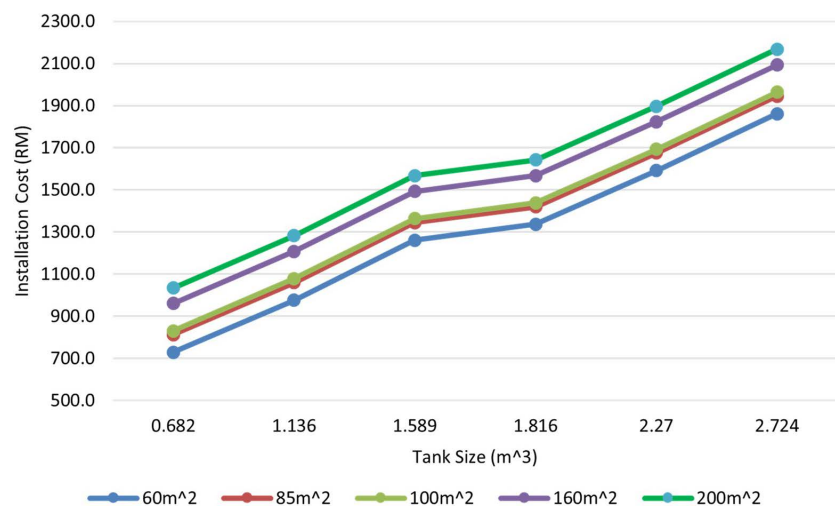


Figure 7. Installation cost vs tank size.

Figure 7 depicts the installation cost of RWHS rising as tank capacity increases. The cheapest tank size to install is 0.682 m³, while the tank with the highest installation cost is 2.724 m³. The installation cost for a 0.682 m³ tank ranges from RM729.03 to RM1034.94 for different roof sizes. The installation cost for a bigger roof area is slightly higher as it requires longer gutter to collect the rainwa-

ter water and channel them towards the rainwater harvesting tank. The cost analysis showed that the installation cost for a tank with a volume of 1.136 m³ can range from RM976.53 to RM1282.44; RM1261.53 to RM1567.44 for a tank with a volume of 1.589 m³; RM1336.53 to RM1642.44 for a tank with a volume of 1.816 m³; RM1591.53 to RM1897.44 for a tank with a volume of 2.270 m³; and finally, RM1861.53 to RM2167.44 for a tank size of 2.724 m³.

The RWHS cost vs. volumetric reliability graph for various tank sizes can be analyzed with the slope gradient, categorized into gentle and steep slopes. The steep slope illustrates that the system reliability was improved significantly by a small increment in cost. In contrast, the gentle gradient linear line reveals that the system reliability was not much improved even after investing a lot in the system. **Figures 8-12** present the percentage reliability of RWHS for roof sizes of 60 m², 85 m², 100 m², 160 m², and 200 m², respectively.

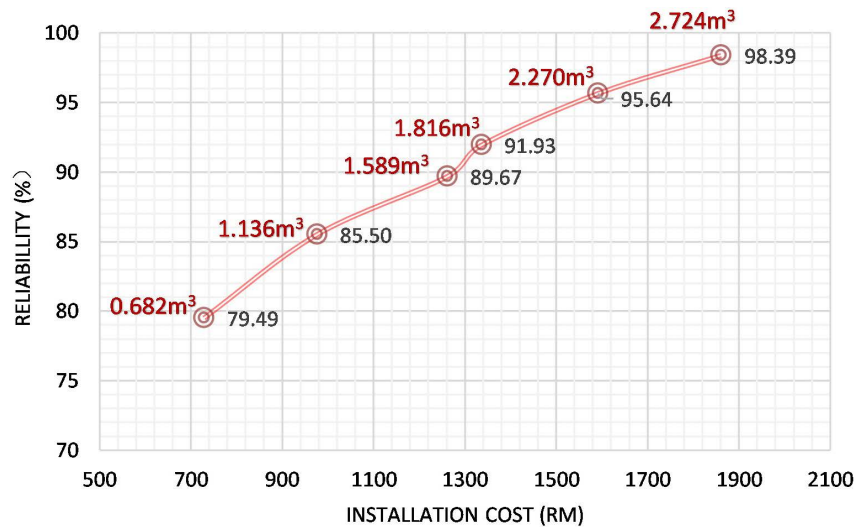


Figure 8. Reliability vs installation cost of various tank sizes for roof size of 60 m².

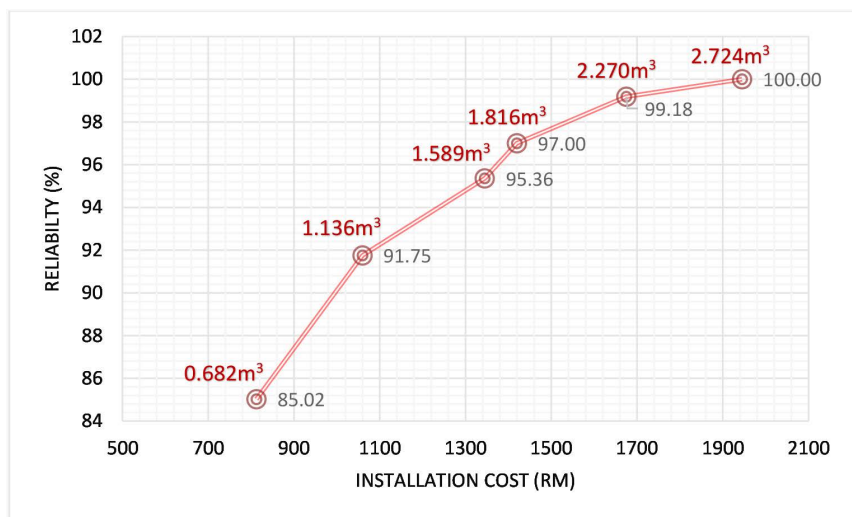


Figure 9. Reliability vs installation cost of various tank sizes for roof size of 85 m².

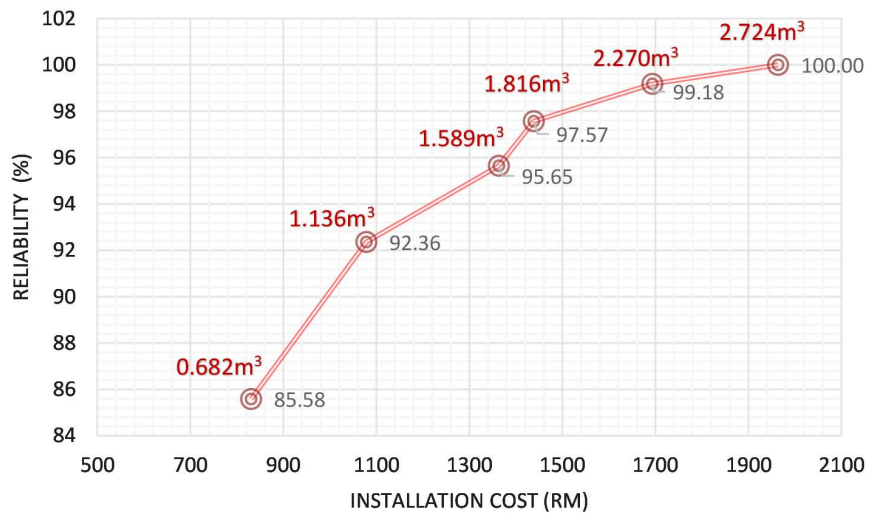


Figure 10. Reliability vs installation cost of various tank sizes for roof size of 100 m².

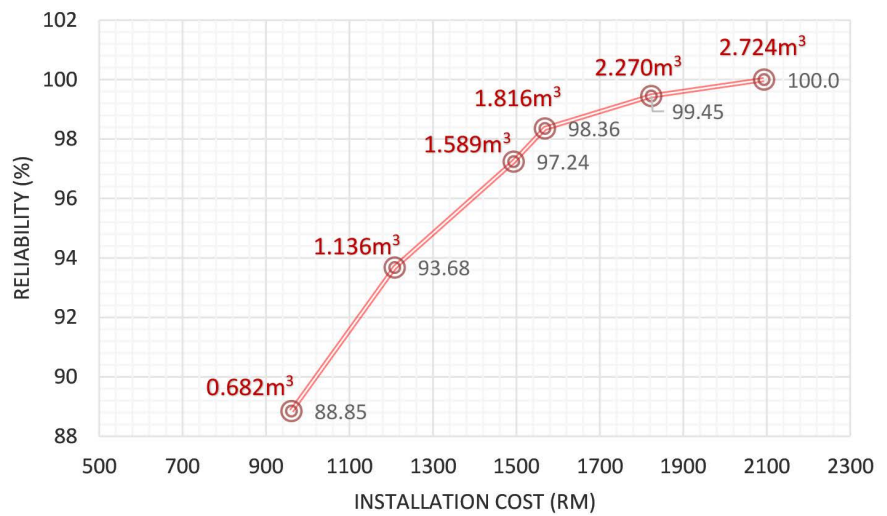


Figure 11. Reliability vs. installation cost of various tank sizes for a roof size of 160 m.

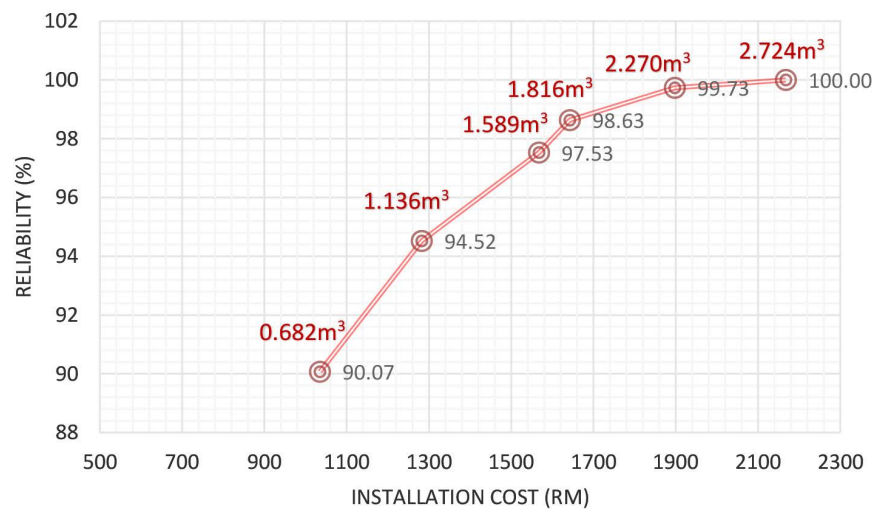


Figure 12. Reliability vs. installation cost of various tank sizes for a roof size of 200 m².

Results revealed that for the roof size of 60 m², the tank size of 0.682 m³ is only able to reach the reliability percentage of 79.49%, which is below the desirable target of 80%. However, a tank size of 1.136 m³ is able to yield reliability up to 85.5%. The total cost for RWHS installation for 1.136 m³ tank size is RM976.53. Cost analysis demonstrated that the total payback period is estimated to be 10.1 years, with a monthly water-saving cost of RM97.

For the roof sizes of 85 m², 100 m², 160 m², and 200 m², the minimum tank size of 0.682 m³ is sufficient to obtain a reliability percentage of more than 80%. With the tank size of 0.682 m³, the roof areas of 85 m², 100 m², 160 m², and 200 m² achieve the reliability percentage of 85.02%, 85.57%, 88.84%, and 90.07%, respectively. The cost analysis revealed that the total installation costs for the roof area of 85 m², 100 m², 160 m², and 200 m² are found to be RM812.46, RM831.00, RM960.78, and RM1034.94, respectively.

The payback period for the roof area of 60 m², 85 m², 100 m², 160 m², and 200 m², and tank sizes of 0.682 m³, 1.136 m³, 1.589 m³, 1.816 m³, 2.270 m³ and 2.724 m³, ranges from 8.4 years to 10.1 years, calculated according to the residential water tariff rate of RM 0.53/m³, charged by the Kuching Water Board (KWB). However, as Sion village is not currently connected to the potable water supply grid, RHWS is the only solution to supply sustainable clean water for this squatter area. Moreover, the RHWS will provide free clean water for this village until the end of the system life span. Therefore, RWHS is feasible to be adopted in this project, and it is a sustainable way to conserve water resources for long-term consideration.

4.4. Limitation

The identification of optimal tank sizes for RWHS faces inherent uncertainties stemming from variations in rainfall, climate change, and fluctuations in demand. The natural variability in rainfall, which includes seasonal and interannual changes, can result in inaccurate assessments of water availability, thereby impacting the reliability of storage. Climate change adds complexity to the sizing process, as alterations in the intensity, frequency, and timing of precipitation may make historical rainfall data less applicable to future scenarios. Furthermore, household water demand is variable, shaped by changes in population, lifestyle modifications, and seasonal requirements. These factors collectively challenge the accuracy of sizing models and underscore the need for adaptive and flexible RWHS designs to maintain performance under changing environmental and socio-economic conditions.

5. Conclusions

This study has successfully determined the appropriate rainwater harvesting tank sizes for different roof sizes in Sion village. The optimal tank size for the roof size of 60 m² was found to be 1.136 m³ with a reliability percentage of 85.50%. Results revealed that the minimum tank size of 0.682 m³ manufactured by WEIDA Poly-

stor HDPE water tank is adequate to achieve the reliability percentage of more than 80% for the roof sizes of 85 m², 100 m², 160 m², and 200 m². The simulation results demonstrated that the reliability percentage achieved using the tank size of 0.682 m³ was found to be 85.02% for 85 m² roof area, 85.57% for 100 m² roof area, 88.84% for 160 m² roof area, and lastly 90.07% for 200 m² roof area.

Referring to cost analysis, the payback period for installing the optimum tank size of 1.136 m³ for 60 m² roof area is 10.1 years. The results revealed that the minimum tank size of 0.628 m³ is adequate to store and supply water to the Sion village with the roof area of 85 m², 100 m², 160 m², and 200 m². As 0.682 m³ tank size is cheaper than other bigger tank sizes, the installation cost would be significantly reduced. The payback period for installation cost for a roof size of 85 m² was found to be 8.4 years, followed by 8.6 years for a roof area of 100 m², 9.5 years for a roof area of 160 m², and lastly 10.1 years for a roof area of 200 m². It was observed that the installation cost is proportionate to the roof area as wider and longer roof areas require longer rainwater gutters.

In this case study, the RWHS is a sustainable solution to provide hygiene and a safe water supply to the squatters in Sion village. The collected rainwater can be used for potable and non-potable purposes. The reliability percentage of 80% to 89% indicates that the RWHS can supply sufficient water to the squatters in Sion village. The cost analysis revealed that the RWHS system is affordable, with the payback period ranging from 8.4 years to 10.1 years. Meanwhile, collecting rainwater can also help reduce the flood risk that occurs in Sion village and downstream.

Declaration

We here submit the manuscript entitled “Relationship of Roof Areas and Rainwater Harvesting Tank Sizes for Squatter at Sion village, Sarawak, Borneo Island” to be considered for publication. We declare that this is our original research work.

Availability of Data and Material

Data will be made available on reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix: Survey Questionnaire

Section A: Household Information

1) How many people live in your household?

- 2
- 3
- 4
- 5
- 6
- 7
- 8
- More than 8 (please specify): _____

2) What is the age range of household members? (Tick all that apply)

- 0 - 5 years
- 6 - 17 years
- 18 - 59 years
- 60 years and above

3) How long have you been staying at your current residence?

- 0 - 2 years
- 2 - 4 years
- 4 - 6 years
- 6 - 8 years
- 8 - 10 years
- Others (please specify): _____

Section B: Water Usage Patterns

For each activity below, please estimate the **average daily water use** per person.
(If unsure, provide your best estimate.)

Activity	Approximate volume used daily (liters)	Frequency per day
1. Drinking	_____ liters	_____ times
2. Cooking	_____ liters	_____ times
3. Personal hygiene (bathing, hand washing, brushing teeth, etc.)	_____ liters	_____ times
4. Laundry	_____ liters	_____ loads/day
5. Utensil washing	_____ liters	_____ times
6. House cleaning (mopping, etc.)	_____ liters	_____ times/week
7. Toilet flushing	_____ liters	_____ flushes/day

Section C: Water Supply and Storage

1) What is your primary source of water?

- Piped water supply
- River water
- Well water

- Rainwater harvesting
- Bottled water
- Others (please specify): _____

2) Do you use any water storage system at home (e.g., water tank)?

- Yes
- No

If yes:

- a) What is the capacity of your water storage tank? _____ liters
- b) How often is it refilled? _____ times/week