



Development of a Sustainable Water Supply through Combined Rooftop Rainwater Harvesting and Groundwater System

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KEYWORDS

Water demand
Rooftop rainwater harvesting
Groundwater system
Sustainable water supply
Water quality

ARTICLE HISTORY

Received 1 February 2025
Received in revised form
11 March 2025
Accepted 15 May 2025
Available online 3 June 2025

ABSTRACT

Increased population often leads to water supply deficit as the demand for water rises. In water resource, rainwater harvesting (RWH) holds great potential for providing a sustainable water supply in Malaysia, while groundwater serves as an alternative water source especially in limited surface water places. This study aims to evaluate the feasibility of sustainable water supply system that combines RWH and groundwater. The first objective is to design an integrated RWH and groundwater extraction to meet the required water demand. The second objective is to evaluate the groundwater quality index on the groundwater based on Malaysia's National Water Quality Standards. This study was conducted at UiTM Kampus Jengka, Pahang. The first step of the methodology involves evaluating the efficiency of the rainwater harvesting system by comparing monthly rainfall from April to September 2024 against the volume of harvested rainwater. In general, volume of shortfall in rainwater supply in UiTM Jengka is about 5m³ per month. In this study, volume of monthly harvested rainwater ranges from 2.74m³ to 4.25m³. The second step was to identify volume of water needed for landscaping purposes around campus of UiTM Jengka which is about 6.3m³ per month. Finally, the water quality index was assessed through laboratory testing of the groundwater sample, using four different types of treatment. This process could evaluate the suitability of the groundwater for consumption and guide on future treatment processes for more efficient use. It is found that the harvested rainwater was not sufficient to meet the area's water demand on most days for landscaping purpose, necessitating reliance on groundwater. Moreover, the water quality index for groundwater was only complied with the required standards for non-potable uses, such as general cleaning, livestock consumption, and landscaping. It is recommended that the groundwater undergo additional treatment, particularly for the removal of heavy metals, to ensure consumer safety.

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1. INTRODUCTION

Malaysia, characterized by a tropical climate, enjoys relatively abundant water resources, with high monthly rainfall levels ranging from 202 mm to 319 mm. The country has not faced a severe water shortage in recent decades. In extreme cases, the country can receive up to 600 mm of rainfall in a single day between November and February (www.worldweatheronline.com). In contrary, some countries such as in Iran, the annual rainfall ranges from only 18mm to

54mm per year [1]. This highlights Malaysia's significant annual and monthly rainfall levels [2]. However, despite this abundance, water scarcity remains a challenge in some areas, exacerbated by a 1.5% annual population growth, global climate change and increasing industrial activities [3,4,5]. The daily water consumption per Malaysian is between 209 and 228 liters per day (lcd), significantly higher than the 165 liters per day recommended by the World Health Organization [29,31]. This high consumption is partly attributed to the relatively low

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<https://doi.org/10.56532/mjsat.v5i2.477>

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water prices in Malaysia (0.26 USD/m³) compared to neighbouring countries like Indonesia (0.51 USD/m³) and Singapore (2.39 USD/m³) [29]. To address water demand issues, especially during dry spells, a reliable water delivery and storage system must be carefully planned. Both private and public water management agencies are advised to adopt integrated water management practices. A system that is nearly self-sufficient in water resources would be considered sustainable. To achieve self-sufficiency, alternative water sources, such as rainwater harvesting (RWH) and groundwater abstraction, should be utilized to supplement the public water supply and improve water security [1,33]. These alternative sources can serve non-potable purposes as well as provide potable water in areas with limited resources or frequent supply interruptions and can provide reliable and cost-effective domestic water [5,6].

In suburban and rural areas, the aging pipe systems and poor maintenance of public water infrastructure often led to leaks, which frequently disrupt the water supply. As a result, it is crucial to explore solutions to address these challenges by identifying alternative water resources. Rainwater harvesting (RWH) and groundwater abstraction are among the viable options for areas facing water shortages or frequent disruptions in supply. The practice gained momentum after the drought in 1998, when the Ministry of Housing and Local Government introduced rules to promote RWH [29]. A study on resource recovery from water [7] suggest that RWH can help reduce costs and the reliance on treated water, positioning it as a viable alternative water resource [8]. Despite the growing interest in RWH, its implementation has been limited due to challenge like seasonal variability and water quality [9,10]. A study by [10] concluded that while Malaysia is well-suited for rainwater harvesting and it can be a valuable solution to water shortages, it cannot always be a completely reliable source due to uneven rainfall distribution in some regions or during certain periods.

To enhance the effectiveness of the rainwater harvesting (RWH) system, other natural water sources can be considered. For example, a dual water supply system combining rainwater and groundwater could be implemented. A related study by [2] highlighted the installation of a water trough on the roof, with a large hot-dipped galvanized steel tank used to direct rainwater to the pump. Two water storage tanks were set up, one for rainwater and the other for groundwater. In the event of water supply issues, the combined storage in both tanks ensures an adequate supply for daily use. Groundwater serves as a viable alternative in areas with limited surface water resources. It is a renewable resource that can be naturally replenished through precipitation [11]. Groundwater is often preferred for various uses over surface water due to its dissolved minerals and other unique properties [12]. Typically, groundwater is of high quality and less affected by seasonal fluctuations [13]. In Malaysia, however, groundwater usage is relatively low, largely due to underestimating the potential of this hidden resource. Previous studies have been conducted by [22] regarding dual water supply system, however the quality of groundwater were not assessed which is crucial since groundwater contain many chemical composition. Therefore, to fully assess the viability of groundwater as a water source, a comprehensive study is necessary. Moreover, while rainwater and groundwater are complementary resources, there is a potential downside to rainwater harvesting. The increased collection of rainwater can reduce the volume of water available

to recharge the aquifer, creating a negative impact on groundwater users in the region.

The quality of harvested rainwater is a crucial consideration, especially if it is to be used for drinking purposes [14]. The quality of rainwater collected from rooftops depends on surrounding factors such as the condition of the rooftop, temperature and air pollution [15]. Before rainwater can be used as drinking water, tests are necessary to assess its safety and suitability [16,17]. Previous study by [18] have shown that the quality of harvested water does not always meet the required standards, primarily due to the lack of proper protection during collection. However, local treatment processes can often make harvested rainwater potable. Alternatively, rainwater can also be considered a non-potable resource for uses such as washing, toilet flushing, and gardening, where water quality is less critical. RWH was collected using roof of building instead of collected by roads, terraces or courtyards due to its low concentrations of chemical and microbiological pollutants, low hardness and salt concentration [19]. In such cases, treatment is not a priority and the water is primarily used for household tasks rather than for drinking.

Groundwater is a complex matrix in which many chemical species are present [3,14]. The quality of groundwater resources is just as important as their quantity, and therefore, it is essential to consider both aspects when managing these resources. In addition to water scarcity, the rapid agricultural and urban development in arid and semi-arid regions has led to a growing demand for groundwater [14]. However, the significant risk of contamination presents a major challenge. As a result, monitoring groundwater quality is a crucial component of water resource management, particularly for areas with groundwater as primary source of drinking and household water consumption [14]. Factors such as rainfall quality and quantity, geological formations, and aquifer mineralogy can all impact the chemical composition or hydrogeological properties of groundwater [20,21]. Therefore, comprehensive studies are needed to evaluate both the quality and quantity of groundwater. The studies can help determine whether groundwater is chemically suitable for drinking or only for non potable water such as agricultural purposes. Additionally, research on groundwater quality in some region has shown that the water quality falls within the "appropriate for agriculture" category, with concentrations of chemical parameters generally below the established warning levels over much of the plain [12].

In light of these assessments, it is expected that the combination of RWH and groundwater system could meet the amount of water demand efficiently in some areas. It is because RWH alone is unlikely to fully meet the water demand especially during the dry season. The aim of this study is to develop a dual water supply system that integrates both rooftop rainwater harvesting (RWH) and groundwater abstraction as alternative water sources to meet water demand, while promoting sustainability and resource conservation. This study will also evaluate the quality of groundwater collected through a well-maintained system based on 4 different treatment, which is lacking in previous studies for this combined water system. The specific objectives are: a) to design a dual/combined water supply system that integrates both rooftop RWH and groundwater as alternative sources of water; and b) to classify the water quality index of the groundwater based on the Malaysia's National Water Quality Standards.

2. METHODOLOGY

2.1 Selection of the Study Area

This study was conducted at the existing building in Universiti Teknologi MARA (UiTM) Pahang, Kampus Jengka. The location of the building is at the coordinate 3.454833N,102.337333E, within the campus. The existing building for rainwater harvesting located about 65 feet distance from the existing tube well, where the groundwater will be extracted. Therefore, the rainwater harvesting water tank will be placed next to the mentioned existing building. Locality map in Figure 1 shows the location of the existing building and tube well, highlighted with yellow line box. This is where the rainwater will be harvested and groundwater extracted.

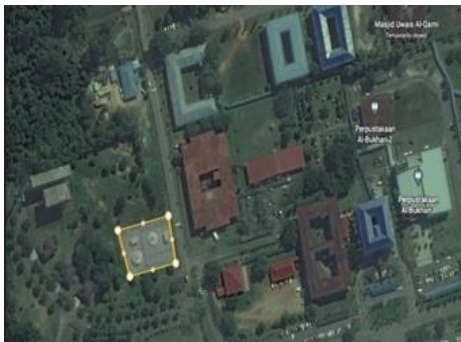


Fig. 1. The location of the rainwater catchment, 3.454833 N,102.337333 E (source: google earth)

The existing building is selected as the best place for the catchment area, considering it is only 65 feet distance from the tube well. Hence this will allow close investigation of the rainwater and groundwater dual water supply system. Besides that, the location is well equipped with existing facilities, which facilitates the activity of harvesting rainwater and integrates with the water pumped from the tube well. In addition, pipe supplies and accessories needed for the project can be minimized and making this project relevant and doable. Figures 2a, 2b and 2c show the condition of selected case study. The catchment area covered are based on area of the existing building rooftop, 13 feet x 13 feet. As suggested, rainwater was collected by two (2) existing buildings at the site.



Fig. 2a. The main gate of the proposed location of the rainwater catchment.



Fig. 2b. The existing building for rainwater harvesting and existing water tank of the groundwater system.



Fig 2c. The existing tube well is just right outside the main gate of the proposed site

2.2 Designing the RWH system and Water Demand

During the first phase, the combined groundwater and rainwater harvesting (RWH) system were assessed and designed. Pumping tests was conducted to the groundwater to evaluate the hydrogeological properties. Meanwhile, the design of the RWH system was referred to the Nahrim Technical Guide No.2 for RWH Systems (Nahrim, Malaysia). The system's primary components include the rainwater tank, conveyance system, and rooftop. During rainfall, water is directed to the tank through gutters and downpipes, where it is temporarily stored for later use. The gutter's width is consistently half its depth (Department of Drainage & Irrigation Malaysia). The gutter for the rooftop rainwater harvesting was designed with a gradient to ensure smooth flow of rainwater through the delivery pipe into the tank. Quality control in the system is supported by complementary devices such as first flush diverters and debris screens. The diverter prevents the initial flow of rainwater from entering the tank, ensuring cleaner water is collected. RWH system was installed after the design phase is completed.

Increased populations/residences in UiTM Jengka in 2024 leads to water supply deficit as the demand for water rises. The amount of water deficit vs water demand for landscaping has been calculated and is shown in Table S1. The amount of rainwater demand for this research is determined by daily activities, including general cleaning, landscaping, and plant watering within the campus. Thus, the effectiveness of the rainwater storage tank are influenced by the water demand. Figure 3 shows the constructed water tank for combined system of rainwater harvesting and groundwater.



Fig. 3. Constructed water tank for dual System

2.3 Rainwater Collection

Rainfall data for this project were collected and recorded using ‘HOBO tipping bucket rain gauge’ from April 2024 to September 2024. These 6 months period was selected based on the completion time of the newly constructed RWH system. The rain gauge was installed on a levelled platform on the building to ensure that there were no surrounding obstacles. The calibration method carried out to ensure the instrument accurately measures the amount of rainfall. The process includes checking the rain gauge’s mechanical components, ensuring it tips at the right volume, and making necessary adjustments. Three rain gauges were installed on the mentioned site and measurement were recorded weekly. Average weekly precipitation from the 3 three rain gauges were calculated each week, which is 4 weeks for each month. Monthly precipitation was obtained from the total of average data from week 1 to week 4. Table S2 shows the details of rainfall data collection for this research with low standard deviation (dataset will be publicly accessible for future research). To obtain the efficiency of the RWH system, the actual amounts of harvested rainwater were finally measured. The potential and actual water collection was estimated using Eq. 1 and Eq. 2 [22].

$$\text{Potential monthly water collection (m}^3\text{)} = \text{Monthly precipitation (m)} \times \text{Roof Catchment area (m}^2\text{)} \quad (1)$$

However, factors such as system inefficiencies, including the roof material, can lead to a minor reduction in water collection. This reduction, referred as runoff coefficient, represents the fraction of rainwater that can be collected from the roof and was calculated using Eq. 2. By comparing the potential and actual amounts of collected water, the analysis provides an accurate measurement of the system's collection efficiency.

$$\text{Actual monthly water collection (m}^3\text{)} = \text{Monthly precipitation (m)} \times \text{Roof Catchment area (m}^2\text{)} \times \text{Collection efficiency} \quad (2)$$

2.4 Combined RWH with Groundwater from Tubewell

For this system, rainwater will be prioritized over groundwater, where it is equipped with automated devices. Float with switching mechanism, will be automatically detected when sufficient rainwater is available. During lower rainwater

level, the device will switch the system back to groundwater, ensuring an uninterrupted water supply to the area. Figure 4 shows the layout plan of dual RWH collection system and the tubewell.

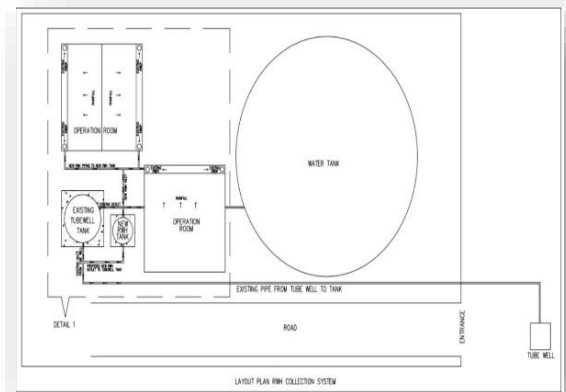


Fig. 4. Constructed combined system of new rainwater harvesting and groundwater from existing tubewell

2.5 Groundwater Sampling for Water Quality Assessment

To classify the physicochemical parameters of the groundwater collected from the tube well at UiTM Cawangan Pahang, a laboratory analysis was conducted, with the results presented in Table 2. A total of four sampling sources (Point A, B, C, and D) were identified at the tube well site. Point A is a raw tube well water; point B is the tube well water after undergo iron removal; point C is the tube well water after undergoing activated carbon treatment and point D is the tube well water after undergo membrane filtration. Four different sampling points based on different water treatment was conducted (with no requirement of ethics approval), to guide future treatment works for the groundwater towards sustainable and efficient treatment for various consumption. The analytical methods used for water quality sampling are: Dissolved Oxygen (APHA 4500-O), Total Dissolved Solids (APHA 2540C), Conductivity (APHA 2510 B), Total Suspended Solids (APHA 2540 D) and Turbidity (APHA 2130B).

The calibration method and quality control were carried out to ensure the accurate measurement for all sampling procedures. The process includes: a. ensures consistent drying and weighing procedures to minimize errors, b. run duplicate samples and blanks for quality assurance, c. calibrate the DO meter using zero oxygen solution (sodium sulfite) and air-saturated water, and d. Ensure the probe’s membrane is clean and electrolyte is fresh (DO meter). For water quality classification, it is based on the National Water Quality Standards (NWQS), which categorize water bodies into different classes depending on their suitability for various uses from Class I to Class V. The NWQS defines limits for physical, chemical, and biological parameters to assess water quality with Class I is clean with practically no treatment is necessary for non-potable use. In this study, the classification is only based on the available data such as DO, TDS, conductivity, TSS and turbidity.

3. RESULT AND DISCUSSION

3.1 Comparison of Rainfall and Harvested Rainwater

Generally, the average daily temperature in UiTM Jengka is approximately 27°C, and experiences significant rainfall throughout the year. However, global warming is expected to affect rainfall in various areas particularly during the drought season which is from May to August [23]. Table 1 presents the monthly rainfall data for UiTM Jengka (the study area), along with the volume of harvested rainwater. From this study, the monthly rainfall data ranges from 93.7 mm to 170.4 mm. The lowest rainfall was recorded in July, whereas the highest precipitation occurs in April. Meanwhile, the volume of harvested rainwater ranging from 2.74 m³ to 4.25 m³, demonstrate the efficiency of the RWH system.

Table 1. Monthly rainfall data and volume of harvested rainwater from April to September 2024

| Month (2024) | Rainfall (mm) | Volume of harvested rainwater (m ³) |
|--------------|---------------|---|
| April | 170± 1.41 | 4.25 |
| May | 164± 0.68 | 4.10 |
| June | 101± 0.79 | 3.53 |
| July | 94± 0.39 | 2.74 |
| August | 125± 1.44 | 3.62 |
| September | 136± 0.89 | 3.74 |

3.2 Water Demand and Water Consumption (RWH and Groundwater)

The amount of water demand and consumption of both harvested rainwater and groundwater are depicted in Figure 5. Overall, most of the monthly harvested rainwater are able to support the usage of the existing groundwater with high volume (i.e 43% to 67% of total consumption) to meet water demand for landscaping purpose around campus of UiTM Pahang with 6.3m³ per month. Nevertheless, there should be no groundwater issues occur in the future to avoid the failure of this dual water supply. Thus, maintaining the efficiency of this combined system is crucial in order to ensure the long-term operation of the system. This renewable source of water could replace the direct consumption of treated water from water treatment plant. The similar system that has been implemented was by [27] which is located at Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor with water demand ranges from 16.5m³ to 18.3m³ as pilot study. In terms of the scalability, this type of combined system can be applied to larger areas, for example in commercial areas [27]. In India's semi-arid regions (Rajasthan), rainwater harvesting structures were constructed to supplement groundwater levels. The study evaluated rainfall-water level dynamics and surface water-groundwater interactions, demonstrating the potential of such integrated systems in water-stressed areas [30].

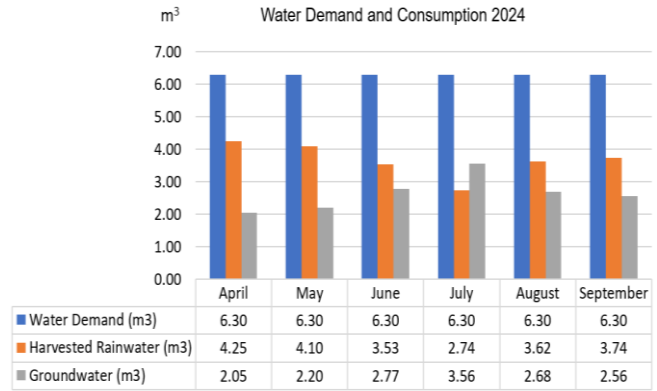


Fig. 5. Volume of groundwater and harvested rainwater needed to meet water demand for landscaping

3.3 Physicochemical Data of Groundwater at Four Different Point Sources

Table 2 shows the parameter from the groundwater sampling such as DO, TSS, turbidity etc. The results were compared to the WHO limit or range for all point A to point D. For temperature, the value changes in the sample may have an impact on ion solubility, either directly or indirectly [24]. The pH of a tube well water sample was slightly acidic and comply with World Health Organization (WHO) Standard. According to [8,24], consumable water's optimal pH range is 6.5 to 8.5. All the samples have low DO which is a rise in water temperature also decreases the solubility of dissolved oxygen [9]. Low DO might also be the consequence of the lack of interaction with atmospheric oxygen. Inorganic reductant substances including hydrogen sulfide, ammonia, nitrites, and ferrous iron, as well as biological processes like respiration and the breakdown of organic matter also contribute to the reduction of oxygen in water [24]. Overall, the measured DO levels of groundwater in UiTM Pahang are greater than those found in prior research by [24]. Although it is a little higher than the results of the other studies, it is still below the WHO-permitted limit of 18 mg/L.

Table 2. Physicochemical data for one month at four different point sources

| Parameters | Point A | Point B | Point C | Point D | WHO Limit |
|----------------------|--------------|--------------|--------------|---------------|-----------|
| Temperature (°C) | 27.87 ± 0.23 | 26.77 ± 0.24 | 26.82 ± 0.14 | 26.74 ± 0.16 | - |
| pH | 7.01 ± 0.16 | 6.25 ± 0.06 | 5.84 ± 0.04 | 5.89 ± 0.01 | 6.5 - 8.5 |
| DO (mg/L) | 6.41 ± 0.16 | 6.72 ± 0.09 | 6.72 ± 0.07 | 6.78 ± 0.04 | 18 |
| TDS (mg/L) | 85 ± 13.31 | 82.42 ± 4.31 | 101.2 ± 5.88 | 122.92 ± 9.33 | 10 - 500 |
| Conductivity (mS/cm) | 0.14 ± 0.01 | 0.11 ± 0.003 | 0.15 ± 0.01 | 0.17 ± 0.003 | 1.5 |
| TSS (mg/L) | BDL | 19.58 ± 2.54 | 4.33 ± 2.10 | BDL | 30 |
| Turbidity (NTU) | 6.63 ± 0.29 | 4.06 ± 1.03 | 2.00 ± 0.34 | 1.91 ± 0.19 | 5 |
| Class | I/IIA | I | I | I | |

Total Dissolved Solids (TDS) in water are various organic and inorganic components that have been dissolved in a specified quantity, including minerals and ions. The observed TDS levels are all below the 1000 mg/L permitted limit set by the WHO. In the Mandalay Region of Myanmar, a study by [25] revealed extremely high TDS levels, ranging from 875 mg/L to 1150 mg/L. This demonstrated that the tube well water in UiTM Jengka still has a low TDS level when compared to earlier studies. Conductivity is a measure of water's capability to conduct electricity, and it is heavily influenced by the ionic species present in the water. These cations and anions in water rely on the ions' mobility at a specific temperature. It is a salinity indicator that has a significant impact on water flavour and reveals the presence of dissolved ions [26]. In Table 2, the mean range conductivity was discovered to be between 0.11 - 0.17 mS/cm. Lower ionizable salts in water are the cause of reduced electrical conductivity [26]. The WHO permitted limit of 1.5 mS/cm was not exceeded by any of the conductivity measurements made from tube well water [27]. The mean conductivity values in Egypt also showed low values which are 1.26, 0.44, and 0.51 mS/cm, according to [27]. Regarding the values of TSS, only sample Point B and Point C have been able to detect the value of TSS while other samples are below detection limit (BDL). In Table 2, the observed mean TSS in sample Point B is 19.58 mg/L while in sample Point C is 4.33 mg/L which are below the threshold value set by WHO which is 30 mg/L and above [9]. Samples with high TSS values may have significant contamination, which might lead to the introduction of many illnesses that impact humans [12,9].

Turbidity in water is caused by the presence of very finely split materials that cannot be filtered using standard procedures [28]. Turbidity in water will have an impact on how well it is received by users. There is a potential that turbidity particles will protect harmful organisms, allowing them to evade the disinfectant's actions [9]. According to [11], the WHO's maximum permissible limit for turbidity is 5 NTU and we can conclude that only the mean turbidity in sample Point A is slightly exceed the permissible limit of WHO. Research done in Nigeria by [12] found that the mean turbidity of tube well water is low, at 0.945 NTU, compared to results from this study. The high mean value of turbidity in Point A is due to corrosion particles, fine organic and inorganic matter, and other microscopic organisms present [12,24]. For the water quality class, all points has been classified as Class I, except for Point A that can be classified as class I/IIA due to higher turbidity value. Sample from Point A is raw tube well water which is without any treatment, resulted to higher turbidity compared to other samples that has treatment. Other reasons for variations in groundwater quality are such as from geological influences and contamination sources. In summary, result of physicochemical data as in Table 2 shows that the groundwater only meet the standard for non potable use only such as for landscaping which currently meet the purpose of this study. Potential improvement in the future such as heavy metals detection and removal is necessary to ensure public health especially for potable water usage.

4. CONCLUSION

It is expected that harvested rainwater could not meet the specified water demand especially during the dry season, thus must be supported by the groundwater. Whereas, the water quality index of groundwater is expected to meet the standards

required for external uses such as general cleaning, livestock drinking and landscaping purposes. This study achieves both expectations where groundwater could support the rainwater source to fulfil the required water demand while meet the standard water quality for external uses. In addition, it will be able to save the use of treated water supply and in turn, can at least reduce the water usage for Universiti Teknologi MARA Kampus Jengka. Furthermore, the research output will educate the campus community on proper water management as well as foster awareness about water consumption, water conservation, and sustainability.

This study could promote the usage of combined rainwater harvesting and groundwater as alternative water supply system in other areas as well, such as in industrial or agriculture sector. This is because water consumption in this study is more likely to be used for outdoor purposes. The development of the dual system will also act as a model or benchmark of innovation and new insight in designing and constructing the alternative water supply system. This study, therefore, fits within the framework of SDG 6, which guarantees the sustainable management of water and sanitation.

While integrating rainwater harvesting (RWH) with groundwater water offers many benefits, there are several limitations and challenges that can affect the success and efficiency of this system. Some of the key limitations are inconsistent or insufficient rainfall during dry period, limited storage capacity that causing overflow, contaminant risks if rainwater harvesting systems if not properly filtered and managed, groundwater depletion risk and require high installation and maintenance cost as well as long term monitoring works. This integrated system's efficiency could be improved by installing high quality filtration for both rainwater and groundwater to remove impurities, increase storage capacity, and use monitoring system to track water usage across both rainwater and groundwater to identify inefficiencies and to optimise resource use. Furthermore, using data analytics tool/real-time control could predict demand, assess the performance of system and identify areas for improvement [32].

Overall, this study has the potential to be enhanced by the collaboration of public and private water agencies or researchers in the production of new external research grants in exploring new technologies that can be adapted for alternative water supply.

ACKNOWLEDGEMENT

This research was supported by Dana Dalaman Negeri granted by UiTM Pahang, Malaysia, Grant Number: 600-TNCPI 5/3/DDN (06) (007/2022)

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