DEVELOPMENT OF DUAL WATER SUPPLY USING RAINWATER HARVESTING AND GROUNDWATER SYSTEMS

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For my beloved father, mother and husband

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ABSTRACT

Demand on water resources has been rapidly increasing and the issue of supplying adequate water to meet societal needs is one of the most significant challenges faced by the provider. Therefore, there is a need to utilise the limited amount of water resources available in a more efficient way. The overall aim of this study was to gain a better understanding on dual water supply system consisting of rainwater and groundwater. The pilot study of the designed system was carried out at the Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor. The data collection was conducted between December 2016 and May 2017 which covers both wet and dry seasons in the study area. For rainwater harvesting (RWH) system, five (5) components namely roof catchment, gutters, down pipe, first flush diverter, and storage tank were successfully designed. Meanwhile, groundwater was pumped from an existing tubewell. Both harvested rainwater and groundwater were then stored in a distribution tank. The first part of the analysis was carried out to assess the RWH efficiency. The monthly results on total volume of collected rainfall in storage tank was 48.97 m^3 while the actual rainfall calculated was 56.04 m^3 with 75% of collection efficiency. A rainfall–storage rating curve was then plotted using 150 rain events data versus the volume of harvested rainwater collected within the study period. The second part of the analysis was to determine the groundwater transmissivity (T), hydraulic conductivity (K) and the water well yield by conducting a step drawdown and constant pumping tests. Electrical resistivity method (ERM) was first conducted to determine the depth of the existing tubewell. The results showed that the depth of the well was 20 m. Transmissivity (T) and hydraulic conductivity (K) values were 1.45 m^2/d and 0.0725 m/hr, respectively. Meanwhile for daily discharge rate, the well was capable to supply water approximately 1.69 m^3. In the current study, the daily water demand was 0.59 m^3, which gave the total volume per month approximately from 16.5 m^3 to 18.3 m^3. Based

on the performance of the system, most of the days rainwater could not meet the water demand, thus have to be supported by the groundwater. Rainwater Harvesting and Groundwater system (RHaGs) calculator was then developed from the generated rainfall–storage rating curve equation. By using the calculator, users can estimate the total volume of rainwater that can be collected and the amount of groundwater needed to cater the water demand. Overall, it can be concluded that dual water supply using rainwater and groundwater systems will contribute to a sustainability and environmental friendly method for restoring and conserving the natural water sources.

ABSTRAK

Permintaan terhadap sumber air telah meningkat dengan pesat dan isu membekalkan air yang mencukupi untuk memenuhi keperluan masyarakat adalah salah satu cabaran paling rumit dihadapi oleh para pembekal. Oleh itu, terdapat keperluan untuk memastikan penggunaan sumber air yang terhad ini dengan cara yang lebih berkesan. Tujuan keseluruhan kajian ini adalah untuk mendapatkan pemahaman yang lebih baik mengenai bekalan air yang terdiri daripada sistem air hujan (SPAH) dan air bawah tanah. Oleh itu, satu kajian telah dijalankan di Universiti Tun Husein Onn Malaysia, Batu Pahat, Johor. Pengumpulan data telah dilakukan di antara bulan Disember 2016 sehingga Mei 2017 yang merangkumi musim basah dan kering di kawasan kajian. Bagi sistem penuaian air hujan (SPAH), lima (5) komponen iaitu tadahan bumbung, ‘gutter’, paip, ‘first flush diverter’, dan tangki simpanan telah dipasang di kawasan kajian. Manakala air bawah tanah dipam dari telaga tiub sedia ada. Kedua-dua air hujan dan juga air bawah tanah disimpan di dalam tangki agihan. Bagi bahagian pertama kajian, penilaian bagi kecekapan SPAH telah dijalankan. Jumlah keseluruhan air hujan yang dikumpulkan dalam tangki penyimpanan ialah 48.97 m^3 manakala hujan sebenar yang dapat dikumpul melalui kaedah pengiraan adalah 56.04 m^3 dengan menggunakan 75% nilai kecekapan pengumpulan. ‘Rainfall–storage rating curve’ kemudiannya dibangunkan menggunakan 150 data hujan dengan jumlah air hujan yang dituai dalam tempoh kajian. Bahagian kedua analisis ini adalah untuk mengenalpasti nilai keterusan (T), konduksi hidraulik (K) dan kadar pengambilan selamat air bawah tanah. Kaedah resistiviti elektrik (ERM) telah dijalankan untuk menentukan kedalaman telaga tiub sedia ada. Keputusan menunjukkan bahawa telaga mempunyai kedalaman 20 m. Keterusan (T) dan konduksi hidraulik (K), masing – masing menunjukkan nilai 1.45 m^2/hari dan 0,0725 m/jam. Sementara itu, untuk kadar pengambilan air bawah tanah yang selamat, telaga tiub tersebut mampu membekalkan air sebanyak 1.69 m^3 sehari. Pengiraan bagi permintaan air dalam masa sehari ialah 0.59 m^3, yang memberikan jumlah keseluruhan sebulan kira - kira 16.5 m^3 hingga 18.3

m^3. Berdasarkan prestasi sistem, air hujan tidak dapat memenuhi permintaan air dikebanyakan hari, oleh itu sistem SPAH perlu disokong oleh air bawah tanah. Kalkulator bagi sistem penuaian air hujan dan sistem air bawah tanah (RHaGs) kemudiannya dibangunkan. Kalkulator ini akan dapat membantu pengguna dan penyelidik di masa hadapan bagi menganggarkan jumlah air hujan yang dapat dikumpulkan dan jumlah tanah yang diperlukan untuk memenuhi permintaan air. Secara keseluruhannya, dapat disimpulkan bahawa bekalan air menggunakan air hujan dan air bawah tanah akan menyumbang kepada kelestarian dan kaedah mesra alam untuk memulihkan dan memulihara sumber air semula jadi.

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LIST OF SYMBOLS AND ABBREVIATIONS

A_c – Area of catchment

A_h – Surface area

A_v – Vertical Area

i – Rainfall intensity

L – Liter

RWH – Rainwater Harvesting

RHaGs – Rainwater Harvesting and Groundwater System

S_t – Tank size

UTHM – Universiti Tun Hussein Onn Malaysia

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CHAPTER 1

INTRODUCTION

1.1 General

Water is essential for the survival of human in everyday life. A majority of human activities involve the use of water such as drinking, washing, and cooking. Despite abundant water resources, the increasing population, urbanisation, and industrialisation have imposed an outstanding demand on the water resources and this has become a global issue (Traboulsi and Traboulsi, 2017). In addition, vast development in urban areas has increased the imperviousness of the land, which affects and alters hydrological processes. Therefore, many nations suggested alternative water supply, which is vital for long term consideration, as humankind may face a water crisis in the future.

Rainwater harvesting (RWH) is one of the ancient practices used in this world to cope with water supply needs. The ancestors have used the rainwater as potable or non-potable water source for their daily activities. In general, RWH is seen as the most excellent practice of rainwater accumulation from rooftops, land surfaces, and road surfaces with a proper storing method for the beneficial purpose instead of allowing it to run off (Jones and Hunt, 2010; Campisano *et al.*, 2017; Zavala *et al.*, 2018). During previous historical drought events, numerous countries adopted strategies to conserve available water resources and promote the usage of RWH to cater water demand (Jones and Hunt, 2010; Christian Amos *et al.*, 2016; Lopes *et al.*, 2017).

Groundwater is another natural water that is sourced from underground. In general, groundwater is water below the ground that is found in the spaces between particles of rock and soil, or in crevices and cracks in rocks. In Malaysia, groundwater comes from various types of aquifers such as shallow and deep alluvial, hard rock, peat, and island. A recent study by Fahnline (2013) reported that Malaysia uses 60%, 35%, and 5% of groundwater for domestic, industry, and agriculture, respectively. Generally, groundwater is used in the abstraction well-operating activities for agricultural, industrial, and municipal purposes (El-Naggar, 2010). However, in areas with low water table, RWH system is commonly used to recharge the groundwater.

1.2 Problem Statement and Motivation

As consequences of growing population, rapid development, industrialization, pollution plus climate change, the demand of water resources in Malaysia is increasing (Law and Bustami, 2013; Ahmed *et al.*, 2014; Oh *et al.*, 2018). These demands include domestic and non-domestic water consumption. Malaysian's water consumption per capita per day increases about 7.6 litres per year (Sung, 2011) Worryingly, the increase in water consumption is not matched by an increase in water reserves. Since 2005, Malaysia's water reserves per capita per day is declining at a rate of 5.8 L per year. At this rate, Malaysia would be left with nearly no water reserve by 2025. These situations will lead to competition for water among users. Future surface water resources development will require the construction of more storage dams since the readily available portion of surface water resources has already been developed for use in practically all regions of major water demand.

Rainwater harvesting (RWH) and groundwater abstraction are among the solutions to the problem in the areas that have inadequate water resources or face long-term water supply disruptions. The abundance of rainfall indicates that RWH has a good potential as an alternative water supply in Malaysia. Apart from that, the adoption of RWH can also contribute towards reducing flash floods. Although RWH is gaining much interest, the implementation has been limited due to several disadvantages such as seasonal variation and related cost (Che-Ani *et al.*, 2009; Lee *et al.*, 2014; Ayob and Rahmat, 2017; Traboulsi and Traboulsi, 2017). However, most of these problems can be solved by making a system with more than one purpose and this includes dual water system with rainwater and groundwater.

Rainwater and groundwater are two interdependent water sources. However, people who harvest rainwater generate an additional negative impact on groundwater users. In other words, although the technology of RWH system may allow us to collect the runoffs, it also causes decreasing amount of water available to replenish the aquifer. Therefore, the motivation of this study is to develop a water supply system that integrates both rooftop RWH and groundwater abstraction.

1.3 Objectives

The overall aim of this study is to gain a better understanding on dual water supply consisting of rainwater and groundwater systems. The objectives of this study are:

1) To determine the efficiency and correlation between rainfall and rainwater collection based on the designed rooftop rainwater harvesting system.
2) To determine the hydrogeology properties at the study area.
3) To develop a calculator for water estimation from both harvested rainwater and groundwater to meet the water demand.

1.4 Scope of Study

The present study focuses on the utilisation of RWH system and groundwater abstraction. It is set to be a significant improvement on RWH systems since it is not well received by users in Malaysia. The development of this pilot system was carried out at the Universiti Tun Hussein Onn Malaysia (UTHM), Johor. The system was installed at a building with a catchment area of 100 m^2 and was designed to fulfill the non-potable indoor house usage. The design of the RWH system was fully referred to the Urban Stormwater Management Manual for Malaysia MSMA (2012) by the Department of Drainage and Irrigation (DID) and NAHRIM technical guide No 2: The design guide for rainwater harvesting systems (2014). The design work was also assessed with the international standards and manuals to improve the efficiency of the operation system which were found in the literature. RWH system in the present study consisted of roof catchment, downpipe, gutter, first flush diverter, storage tank and distribution tank. For rainfall observation, the rainfall data was obtained from the installed rain gauge starting from December 2016 until May 2017. The volume of rainfall captured in the storage tank was measured. The observed volume was then compared with the calculated values using rational method formula. By comparing these values, the collection efficiencies of the system was determined. Meanwhile, groundwater was abstracted from an existing tube well. In order to determine the tube well depth, electrical resistivity method (ERM) was carried out and analysed using 2D resistivity inversion (RES2DINV) software. Pumping test was also carried out to determine the hydrogeology properties which includes transmissivity, T, hydraulic conductivity, K and the groundwater yield.

1.5 Significance of Study

In Malaysia, many water-related problems have raised concerns among the water engineers and the public. It is a problem of not managing water effectively to achieve desired objectives. Therefore, any attempt to manage water resources will have to consider both the management of excess water (floods) and insufficient water (droughts). This research has many benefits not just for the users but also to the government. The study adopted the RWH system and its utilisation as part of the conservation of natural water resources and may also become the solution to the aforementioned problems. Moreover, it supports the Ninth Malaysia Plan: Vision 2020 (Ministry of Malaysia, 2006), in which Malaysia will conserve and manage its own water resources to ensure adequate and safe water for all, including the environment. To ensure the system can be fully utilised regardless of any season, groundwater is another suitable water resource. With the integration of these two sources of water, the users will benefit accordingly without relying on treated water.

1.6 Outline of the Thesis

Chapter 1 describes the background of the research study, the objectives, and the research significance. This chapter also outlines the limitations of the study and the specifications about the data and design that were used.

Chapter 2 presents a comprehensive literature review related to the topics. This chapter identifies the current state of knowledge and research gaps in rainwater harvesting and groundwater management. The work presented here has been published in *MATEC web of conferences*.

Chapter 3 provides a description of the study area, water demand, and rainwater harvesting design. This chapter also presents the procedures of groundwater abstraction and the development of rainwater harvesting and groundwater system (RHaGs) calculator.

Chapter 4 discusses the calculation and design process of RWH systems. This chapter also explains the results of actual and observation harvested rainwater. In addition, the rainfall-storage rating curve are also presented. The work presented here has been published in *Jurnal Teknologi*.

Chapter 5 presents the results of the preliminary study carried out to determine the depth of existing tube well. This chapter also discusses the results of pumping test for groundwater abstraction and the water balance estimation. The work presented here has been published in *International Journal of Integrated Engineering*.

Development of the rainwater harvesting and groundwater system (RHaGs) calculator is presented in Chapter 6. The calculator has been registered in intellectual property protection under UTHM with serial no. LY2017005058.

Finally, Chapter 7 presents the conclusions of the research with some recommendations for future improvement.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents a critical literature review on water demand, issues that are relevant to RWH such as the design and implementation, and the exploration of groundwater. These aspects of RWH and groundwater have been widely discussed in the literature and still remain major research topics.

2.2 Water Usage

Water consumption are usually varies according to the lifestyle, places and living standards, hence, there is no standards or outlines to highlight the average water consumptions to the certain places. However, water demand is usually calculated based on the household consumptions patterns or appliances by using social survey method (Borg *et al*., 2013; Loh and Coghlan, 2003). According to Lu (2007), household water consumptions includes drinking water, food preparation, bathing, washing clothes, flushing toilets, and watering lawns and gardens.

A study in the United States conducted by Borg *et al.* (2013) found that 50% of total water was used from the showers. This result was similar to Lu (2007). He reported that in Eastern African, only small quantities needed for drinking and cooking and the large amount of water was used for bathing, cleaning and washing. Table 2.1 shows several results on the water consumptions pattern in certain places while Table 2.2 shows average appliance consumption in the United Kingdom, Finland, France and Germany

Table 2.1 Average daily per capita water consumption for households (Loh and Coghlan, 2003; Lu, 2007; Grech, 2012; Borg *et al.*, 2013)

Location	Household water use composition (%)			
	Shower	**Laundry**	**Dish Washing**	**Toilet**
Western Australia	33	27-26	16-21	17-21
Malta, Europe	34	18	20	9
Davis, California	51-58	9-16	15-17	12-27
China	26-31	12-25	17-32	25-32

Table 2.2 Average appliance consumption in the UK, Finland, France and Germany (Lu, 2007)

Appliances	United Kingdom	Finland	France	Germany
Toilet	9.5 L/flush	6 L/flush	9 L/flush	9 L/flush
Washing Machine	80 L/cycle	74-117 L/cycle	75 L/cycle	72-90 L/cycle
Dishwasher	35 L/cycle	25 L/cycle	24 L/cycle	27-47 L/cycle
Shower	35 L/shower	60 L/shower	16 L/shower	30-50 L/shower
Bath	80 L/bath	150 L/bath	100 L/bath	120 L/bath

Though Malaysia is endowed with abundant water resources, the country has been experiencing increased demand for water in recent years. In the 1970s, a person in Malaysia used less than 200 L of water per day. The amount increased to 250 L in 1980s and now more than 300 L (Chan, 2016). As comparison, the water use recommended by the United Nations for Malaysia is only 200 L (Hasan, 2013). The increment in water consumption does not match with the increase in water reserves, at which the declining rate is 5.8 L per year as illustrated in Figure 2.1. In 2015 and 2016, the average water consumption per capita per day was 209 L (Table 2.1) and can be classified as unsustainable. These consumptions are far beyond the water usage recommended by the World Health Organization (WHO), which is only 165 L per day.

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