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SUSTAINABLE GROUNDWATER EXTRACTION FOR AGRICULTURE USE AT BUKIT MERAH AQUIFER IN SEMANGGOL, PERAK, MALAYSIA

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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February 2020

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Sufficient water supply is required by paddy plants at all growth stages for high yields. Although Malaysia receives an annual rainfall of about 3,000 millimeters, which is above the global average, climate change such as El-Nino can influence the amount of rainfall leading to prolong drought. The uncertainty of climate patterns and the high dependency of the country on surface water resources have worsened the water supply situation. Paddy cultivation around the district of Kerian which obtains irrigation sources from Bukit Merah Dam was severely affected during the phenomenon. Surface water that is easily affected by climate change causes water supply crisis and inability to supply the irrigation source. Therefore, an alternative source of groundwater that could be extracted needs to be studied to have sustainable supply of water for agricultural purposes. The main objective of this study was to evaluate the sustainable groundwater extraction for agriculture use in Bukit Merah, Semanggol, Perak. The groundwater model was developed using Visual MODFLOW to simulate sustainable groundwater extraction without environmental effect. The lithological formation of the study area was constructed using wells information and assisted with resistivity survey using pole-dipole arrangement. The electrical resistivity tomography (ERT) profile was interpreted with reference to geological map to determine the types of rocks that underlie the area. A 4-layer model was developed to represent the lithological formation of the study area; unconsolidated deposit, sedimentary, metamorphic, and granite layer. Then, the conceptual model was built using geological and hydrogeological data of the study area. The model was calibrated to acceptable limits for head observation and chloride concentration. The simulation was done under different pumpings for both normal and extreme-low groundwater recharges. The impact of groundwater extraction on the river and lake system during normal and dry season was assessed. The groundwater flow pattern, groundwater balance and saltwater interface were determined by simulating in-steady state of groundwater flow.

This study has revealed that the sustainable groundwater extraction during normal groundwater recharge is 80,000 m^3/day and 50,000 m^3/day during extreme-low groundwater recharge respectively without any negative impacts on groundwater resource and surrounding ecosystem. In conclusion, throughout the development of groundwater resources in the area, it could be utilized by the farmers around the Kerian area for irrigation purposes especially during droughts.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENGEKSTRAKAN AIR BAWAH TANAH SECARA MAMPAN UNTUK KEGUNAAN PERTANIAN DI BUKIT MERAH AKUIFER, DI SEMANGGOL, PERAK, MALAYSIA

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NORFAEZAH BINTI MAKZIN

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Bekalan air yang mencukupi diperlukan oleh tumbuhan padi pada seluruh peringkat pertumbuhan untuk pengeluaran hasil yang tinggi. Walaupun Malaysia mempunyai hujan tahunan yang banyak sekitar 3,000 milimeter, iaitu melebihi purata global, namun, perubahan iklim seperti El Nino telah memberi kesan kepada jumlah hujan yang membawa kepada musim kemarau berpanjangan. Pola iklim yang tidak menentu dan kebergantungan yang tinggi oleh negara terhadap sumber air permukaan telah memburukkan lagi situasi bekalan air. Penanaman padi di sekitar daerah Kerian yang memperolehi sumber pengairan daripada Empangan Bukit Merah telah terjejas teruk ketika fenomena tersebut. Air permukaan yang mudah terjejas dengan perubahan iklim menyebabkan berlaku krisis bekalan air dan sumber pengairan padi tidak dapat dibekalkan. Lantaran itu, satu sumber alternatif iaitu air bawah tanah yang boleh diekstrak perlu dikaji dengan tujuan membekalkan air secara mampan untuk tujuan pertanian. Objektif utama kajian ini adalah untuk menilai pengekstrakan air bawah tanah secara mampan untuk tujuan pertanian di Bukit Merah, Semanggol, Perak.Model air bawah tanah telah dibina menggunakan perisian Visual MODFLOW untuk membuat simulasi pengekstrakan air bawah tanah tanpa memberi kesan kepada alam sekitar. Formasi litologi di kawasan kajian telah dibangunkan dengan menggunakan maklumat telaga di kawasan kajian dan dibantu dengan kajian keberintangan menggunakan susunan pole-dipole. Profil keberintangan elektrik tomografi (ERT) telah ditafsirkan dengan merujuk peta geologi untuk menentukan jenis batuan yang mendasari kawasan tersebut. 4 lapisan model telah dibangunkan mewakili formasi lithology di kawasan kajian; lapisan tidak padu, lapisan batuan endapan, lapisan batuan metamorf, dan lapisan batuan igneus. Kemudian, model konseptual telah dibina dengan menggunakan data geologi dan hidrogeologi di kawasan kajian. Simulasi telah menggunakan kadar pengepaman yang berbeza-beza bagi kedua-dua keadaan aliran masuk air bawah tanah yang normal dan terlampau

rendah. Impak daripada pengekstrakan air bawah tanah kepada sistem sungai dan tasik semasa keadaan normal dan kering telah dinilai. Pergerakan air bawah, bajet air bawah tanah dan antara muka air masin telah ditentukan melalui simulasi menggunakan keadaan statik dalam aliran air bawah tanah. Hasil kajian mendapati kadar pengepaman yang mampan untuk aliran masuk air bawah tanah pada keadaan normal dan pada keadaan yang terlampau rendah adalah masing-masing sebanyak 80,000 m^3/hari dan 50,000 m^3/hari tanpa memberikan kesan negatif kepada sumber air bawah tanah dan ekosistem. Melalui pembangunan sumber air bawah tanah di kawasan tersebut, ia dapat dimanfaatkan oleh pesawah padi di sekitar daerah Kerian untuk tujuan pengairan terutama ketika kemarau.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

amsl	Above mean sea level
BML	Bukit Merah Lake
DID	Department of Irrigation and Drainage
SPAN	Suruhanjaya Perkhidmatan Air Negara
MMD	Malaysia Meteorological Department
JMG	Department of Mineral and Geoscience Malaysia
JUPEM	Department of Survey and Mapping Malaysia
K	Hydraulic Conductivity
S_s	Specific Storage
S_y	Specific Yield
n_e	Effective Porosity
n	Total Porosity
CC	Correlation coefficient
NRMS	Normalized root mean squared

CHAPTER 1

INTRODUCTION

1.1 Background Study

Water is the most important element needed on earth for survival of human population, plants, and animals. The role of water is extremely important in most daily activities and human economic activities including agriculture, livestock, industry, and others (Griffiths et al., 2010). Facts indicate that the existence of freshwater resources around the world is only 3% where they are distributed in various forms such as icecap, glaciers, groundwater, and surface water (Perlman, 2006).

The main source of fresh water supply in Malaysia depends on surface water such as river, lake, and dam, but in fact, this source has reached the maximum level. Statistic has shown that about two-third of hundreds of river basins in the country have been severely polluted as a result of human activities and thus incurs a high cost of treatment (Ahmad, 2013). Therefore, the groundwater source is the best alternative to replace most of the rivers that are no longer capable of providing fresh water.

At the same time, the demand for water is increasing from various sectors which are mainly affected by population growth, urbanization, industrialization, food, energy security policy and macro-economic processes (Patry, 2011 and UNESCO, 2015). Up to now, the agricultural sector is the largest water user in Malaysia which accounts for about 70% of all freshwater withdrawals (Doungmanee, 2016).

An invariability of rainfall caused by climate change, especially during the drought leads to water supply crisis. Surface water which is easily affected by extreme weather conditions might worsen the situation as the country is too dependent on surface water. In 2015/2016, the El Nino phenomenon hit the country causing an increase in temperature along with reduction of precipitation. The continuous hot and dry weather resulted in desiccation of river flow (Patry, 2011). As a consequence, several states, especially in Perlis, Perak, and Johor had experienced water supply crisis.

According to Ahmad (2013), the total estimated groundwater storage in Malaysia is about 5,000 billion m^3 with additional 64 billion m^3 of rainfall that seep into the soil and replenish the groundwater naturally. However, only 3% of these groundwater reserves is used in this country (Ahmad, 2013). This

indicates that the abundant potentials of groundwater resources in Malaysia have been neglected. Hence, the exploration on the use of groundwater is an alternative to replace the contaminated surface water and at the same time addressing the water crisis.

Therefore, a conceptual model that represents a groundwater flow system covering the geological, hydrogeological and hydrological aspects needs to be built to allow the understanding of groundwater movement. A three-dimensional finite-difference groundwater model, MODFLOW is able to simulate the recharge and discharge area of the groundwater system to perform water management strategy (Batelaan et al., 2003). The identification of lithology of an area is able to determine the location of an aquifer and the volume of groundwater that can be pumped out from aquifer based on hydrogeological properties (Huey, 2017). The development of hydrogeological framework with the emphasis on estimating the flow rate and water balance components is one of the fundamental steps to determine the sustainable use of groundwater on a large scale (Khodapanah et al., 2011).

1.2 Problem Statement

The El Nino phenomenon faced by Malaysia in 2015/2016 has affected water supplies in several states including the state of Perak. This phenomenon has resulted in the depletion of raw water sources either in rivers, lakes or dams due to the lack of rainfall and high evaporation rates in surface water (SPAN, 2016). High dependency on surface water resources in Malaysia has worsened this situation as the surface water properties are easily affected by extreme weather conditions (Ying, 2014).

Bukit Merah Dam, which is an important dam in Perak, had been seriously affected by these phenomena (SPAN, 2016). This dam is the main water source for paddy cultivation in Kerian district known as Kerian Agriculture Scheme. Paddy cultivation experiences two seasons in a year where irrigation water supply is required around 100 days for a season with the total water discharge requirement of 28 m^3/s for 24,000 hectares of rice field (Department of Irrigation and Drainage Kerian, 2010).

As a result of the hot weather, the water level at Bukit Merah Dam had decreased substantially until it reached a critical level of 6.16 meters above the sea level (SPAN, 2016). The existing water level during the phenomenon was no longer able to be channelled to the rice fields. Therefore, the water discharge to the rice fields in Selinsing and Semanggol were temporarily suspended by DID Perak during that time (SPAN, 2016). As a result, an area of 8,097 hectares of paddy fields has been affected involving 3,175 farmers in Kerian district with a loss of rice yields estimated at approximately RM 56 million to be borne by them (Pauzi, 2016).

In order to solve this problem, a comprehensive study on groundwater as an alternative source for agricultural purposes needs to be done immediately (Ayuni, 2015). Tube wells with water extraction from underground is the best way to drain water into the rice fields during dry season (Mamat, 2016). Extraction of groundwater should be initiated with groundwater modelling to ensure sustainable use of water in the study area. Aquifer modelling using the Visual MODFLOW software in Bukit Merah, Semanggol was set up to develop an understanding of groundwater system in the area.

1.3 Objectives

The main objective of this study was to determine the safe yield of groundwater extraction during the El- Nino phenomenon at Bukit Merah Semanggol aquifer. The specific objectives are:

1) To delineate the lithological formation of the aquifer for groundwater abstraction.

2) To develop the groundwater model using Visual MODFLOW software for simulation of the pumping rate.

3) To analyse the potential environmental impacts on groundwater due to the abstraction at different pumping rates.

1.4 Scope of Study

This study focused on the simulation of groundwater flow in the aquifer located in Bukit Merah, Semanggol, Perak using Visual MODFLOW software. All the data for this study were collected to build a hydrogeological framework representing the groundwater system for the study area which included geological studies (well log, topographic), hydrological studies (rainfall data, water level, evapotranspiration) and aquifer properties (hydraulic conductivity, porosity, effective yield, specific storage). The lithology of the study area comprising the aquifer layers and thicknesses was prepared based on the well log data and resistivity survey. Then, the hydrogeological framework was developed. A model was calibrated with groundwater level data for steady-state conditions only to represent the natural groundwater flow. The model was applied to four different scenarios of the groundwater recharge rate. The effects of groundwater pumping on groundwater hydraulic head, groundwater balance and saltwater interface were observed. The results obtained were analyzed to determine the groundwater discharge at sustainable use for the study area.

1.5 Limitations

1) This project was carried out without any funding supports. The input data used to develop the groundwater model relied solely on the secondary data obtained from the government agencies and the data were quantitatively limited. To produce a good groundwater model requires a lot of data points, however, it was a big limitation in this study.

2) The scope of research was to propose sustainable groundwater extraction only. Therefore, the research was limited to calibration part. The validation of model to verify the simulation result in this research was unable to be done as there was none of monitoring wells available in the study area.

3) Herein, groundwater sustainability was assessed environmentally instead of the economic and social aspects. The assessment was particularly focused on surface water depletion and saltwater intrusion which are most likely to happen in the study area. Only dominant surface water within the study area namely Bukit Merah Lake and Kurau River was considered. Small rivers in the study area were not considered due to the impact on groundwater system that is expected to be minimal and unavailability of data.

1.6 Significance of Study

Conducting in-depth hydrogeological investigation at the site usually requires drilling a large number of exploratory wells, pumping test, conducting multiple geophysical surveys and a series of long-term experiments, which are expensive and time-consuming. Computer simulation modelling is one of the alternative methods that can help the responsible parties to view the behaviour of groundwater system in a quicker way and more cost effective. The model can be used to assess the groundwater flow pattern of an aquifer which can provide adequate information for groundwater management.

Unpredictable climate change such as the El-Nino phenomenon has led to water supply crisis. Therefore, the use of groundwater for agricultural purposes is the best alternative to solve these problems. Pumping wells must be constructed to provide water to the paddy fields for irrigation purposes in Kerian area especially during El-Nino. This study can help farmers to cope with the huge loss of paddy yields due to the lack of water supply.

Although it is anticipated that this area will have many groundwater sources for use, optimized pumping must be applied to avoid any negative implications for groundwater and ecosystems especially to the river and lake systems of the area.

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