UNIVERSITI PUTRA MALAYSIA

EVALUATION OF GROUNDWATER RECHARGE BASED ON RAINFALL AND LAND USE CHANGES

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By

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EVALUATION OF GROUNDWATER RECHARGE BASED ON RAINFALL AND LAND USE CHANGES

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The soil water assessment tool (SWAT) is a continuous and distributed hydrologic model created to simulate the effect of land management practices on water in the watershed. Understanding relationship of water extraction of groundwater can lead to better watershed management. The main problem in this study is the complexity of recharge processes and limited observations in groundwater recharge in Malaysia makes it difficult to quantify. This study was done at Baung's watershed (BW) which can be considered as an ungauged watershed. The estimation of groundwater recharge in BW was done using SWAT. A framework for SWAT input data including hydrography, terrain, land-use, soil and weather for BW was then focused in order to achieve the model simulation for ungauged basins. The results emphasize the importance and prospects of using accurate spatial input data for the physically based SWAT model. Normal rainfall condition, extreme-low rainfall condition, normal rainfall under future land use and extreme low rainfall condition under future in land-use development represented as Scenario 1, Scenario 2, Scenario 3 and Scenario 4 were evaluated in this study. These conditions give different groundwater recharge rate as different scenarios give different impact to groundwater. The coefficient of determination, R^2 of the model is 0.9676. Model was found to produce a reliable estimation of groundwater recharge of 405 mm/year (14.6%), 194.12mm/year (11.1%), 214.23 mm/year (7.7%) and 95.55 mm/year (5.5%) for Scenario 1, Scenario 2, Scenario 3 and Scenario 4 respectively. In conclusion, it is suggested that groundwater recharge should not be assume with only one specific value such as 6%, 11% and 26% of annual rainfall as the land use development and rainfall intensity factors influencing groundwater recharge need to be took into consideration in assisting groundwater exploration and management.

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

PENILAIAN TERHADAP PENGIMBUHAN AIR BAWAH TANAH BERDASARKAN HUJAN DAN PERUBAHAN PENGGGUNAAN TANAH

Oleh

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Alat Penilaian Air dan Tanah (SWAT) adalah model hidrologi yang berterusan dan teragih telah dicipta untuk membuat simulasi terhadap kesan amalan pengurusan tanah ke atas lembangan. Pemahaman tentang hubungan pengekstrakan air bawah tanah membawa kepada pengurusan lembangan yang lebih baik. Masalah utama bagi kajian ini adalah proses pengimbuhan yang rumit dan pemerhatian yang terhad dalam pengimbuhan air bawah tanah di Malaysia yang menjadikannya sukar untuk dikira. Kajian ini telah dijalankan di Lembangan Baung (BW) yang boleh dianggap sebagai lembangan yang tiada tolok. Anggaran pengimbuhan air bawah tanah di BW telah dilakukan menggunakan SWAT. Kerangka kerja untuk data masukan SWAT termasuklah hidrografi, maklumat guna tanah, maklumat tanah dan cuaca untuk BW telah difokuskan untuk mencapai simulasi model bagi lembangan tidak bertolok. Hasil daripada keputusan telah menekan kepentingan dan prospek menggunakan data masukan geografi yang tepat untuk model SWAT berasaskan fizikal. Senario 1, Senario 2 Senario 3 dan Senario 4, masing-masing mewakili keadaan yang normal, hujan yang terlampau rendah, dan pembangunan penggunaan tanah pada masa hadapan telah dinilai dalam kajian ini. Keadaan ini memberikan kadar pengimbuhan air bawah tanah yang berbeza-beza kerana scenario yang berbeza memberikan impak yang berbeza kepada air bawah tanah. Penentu pekali, R^2 bagi model ini adalah 0.9676. Model telah didapati menghasilkan anggaran pengimbuhan air bawah tanah sebanyak 405 mm/tahun (14.6%), 194.12mm/tahun (11.1%), 214.23 mm/tahun (7.7%) dan 95.55 mm/tahun (5.5%), masing-masing bagi Senario 1, Senario 2, Senario 3 dan Senario 4. Kesimpulannya, adalah disarankan bahawa pengimbuhan air bawah tanah tidak sepatutnya dianggap hanya dengan satu nilai tertentu seperti 6%, 11% dan 26% daripada hujan tahunan kerana faktor pembangunan penggunaan tanah dan intensiti hujan mempengaruhi pengimbuhan air bawah tanah perlu diambil kira dalam membantu penerokaan dan pengurusan air bawah tanah.

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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

SWAT	Soil and Water Assessment Tool
WTP	Water Treatment Plant
TW	Tube Well
NSE	Nash Sutcliffe Efficiency
GIS	Geographic Information System
BW	Baung's Watershed
UPM	University Putra Malaysia
DEM	Digital Elevation Model
FOMCA	Federation of Malaysian Consumers Associations
HRU	Hydrological Response Units
SI	Soil Investigation
DID	Department of Irrigation and Drainage
DOA	Department of Agriculture
MMD	Malaysian Meteorological Department

CHAPTER 1

INTRODUCTION

1.1 Overview

In recent years, growth, urbanization, expansion of agriculture, logging activities and industrialization have taken place. These changes have caused complex environmental problems such as water pollution, sedimentation and flooding (Camara et al., 2019). Rivers in Malaysia are highly affected by the rapid growth (Camara et al., 2019). Therefore, to ensure the availability of water resources, it is important to safeguard our catchments and river basins without altering the socioeconomic growth. A watershed or also known as a catchment basin is a hydrological unit or a land area with topographical features from which water flows downstream to a shared destination through precipitation and land surface interactions (Li, 2019). A catchment area can be very limited also, it can be just a few kilometres, or it can comprise a wide area (Crooks et al., 2014). The cumulative amount of water dropping as rainfall within the catchment area will either flow through the river as a surface runoff that fills the basin, or sink into the earth to become groundwater (Heath, 1987). Groundwater and surface water are also used for agricultural, industrial and domestic purposes.

Hydrological modelling is a powerful technique of hydrological system investigation used by the research hydrologist and practicing water resources engineers whose involved in the planning and development of integrated approach for the management of the water resources (Guida et al., 2006). With advanced in computational power and the growing availability of spatial data, it is possible to accurately describe watershed characteristics when determining runoff response to rainfall input.

Groundwater is one of the components involved in the natural hydrological cycle process. Infiltration of water into the subsurface until it reaches the water tables forming an addition to the groundwater storage (Freyberg et al., 2015). The groundwater storage in Malaysia is estimated about 5,000 billion m^3 with additional 64 billion m^3 of rainfall that seep into the soil and replenish the groundwater naturally (Ahmad, 2013). Groundwater is an important alternative source in Kelantan to address issues such as climate change that causes prolonged droughts, pollutions in most rivers and rising demand for water supply from various sectors (Zamri, 2019).

In Kelantan, groundwater resources has been utilised since 1935 and the demand has risen till the present time with 70% utilization for domestic water supply purpose (Hussin et al., 2020). Groundwater has been abstracted from shallow and deep aquifer system to meet the demand due to rapid population growth in Kelantan state. The pilot groundwater based projects such as RBF system with horizontal wells, river barrage and groundwater dam within the basin were planned to meet water demand in future (Air Kelantan Sdn Bhd, 2015). Clearly, the role of groundwater resources are important and are being developed in Kelantan to meet consumer demand.

However, overexploitation of groundwater may introduce unprecedented groundwater stress problems in the area such as saltwater intrusion, land subsidence, groundwater depletion, aquifer compaction, arsenic contamination and groundwater quality deterioration (Heath, 1987). Therefore, effective groundwater management is crucial to prevent any environmental issues due to over-exploitation of groundwater in the aquifer system (Alley et al., 1999). A conceptual model that represents a complex hydrogeological system needs to be built to allow the understanding of watershed-scale interactions in the study area (Muhammad et al., 2019). Then, these models can be used to forecast the effects of various anthropogenic activities on groundwater recharge system, making them useful tools for: (1) watershed and water resource planning; (2) evaluation of conservation programs; (3) predict the effects of climate and land use change (White et al., 2017).

Soil and Water Assessment Tool (SWAT) is a conceptual, continuous time model that was developed to assist water resource management by assessing the impact of management and climate on water supplies and non-point source pollution in watersheds and large river basins (Wang et al., 2019). The model components include weather, hydrology, erosion/sedimentation, plant growth, nutrients, pesticides, agricultural management, stream routing and pond/reservoir routing (Arnold et al., 2012).

SWAT was also developed to predict the impact of management practices on water, sediment and agricultural chemicals in watersheds comprising different soils, land-use and management conditions over long time periods (Bokan, 2015; Mishra, 2013; Fohrer et al., 2014). The impact of land-use changes and climate change as well as their combined/interactive effect on water resources can also be predicted through SWAT (Douglas-Mankin et al., 2010). SWAT was also coupled with ecosystem models to study the trade-offs between water quality and ecosystem services (Douglas-Mankin et al., 2010). Application of SWAT model also included the case of arid and semi-arid watersheds (Wheater et al., 2007). Remote sensor data provides valuable geographical and near real-time knowledge about natural resources and physical parameters.

The SWAT model can be built using ArcGIS (Olivera et al. 2006). GIS is an effective tool in watershed modelling as remote sensing derived information can be well integrated with the conventional database for estimating runoff and help in assisting for suitable soil and water conservation measures (Wang et al., 2019). The present study was carried out on the implementation of the SWAT model, which combines GIS knowledge with the attribute database to approximate the recharge rate (Dunaieva et al., 2019).

The SWAT model is feasible and optionable at different time-scales such as sub-daily, daily, monthly and annual with extensive hydrology and pollutant transport applications (Tan et al., 2018). The SWAT information has been extensively and completely documented as the guideline for users (Arnold et al., 2012). At present, many researchers have applied the SWAT model in different watersheds to estimate groundwater recharge such as Yifru et al. (2020) Jin et al. (2015) and Loukika et al. (2021). The simulation results for aforementioned studies show that SWAT has good simulation results at multiple scales and confirmed the adaptability and credibility of SWAT model. Clearly, it is a relatively mature model, and therefore the SWAT model was selected for simulation in this study.

1.2 Problem Statement

Environmental problems have slowly spread too many of Malaysia's river basins with associated problems such as flooding, water pollution and sedimentation (Camara et al., 2019; Salmiati et al., 2017). In order to maintain the quality of water resources, it is important to develop the requisite knowledge and skills to safeguard our catchments and river basins without altering socioeconomic growth. Conducting field tests and gathering long-term data can be expensive (Osang et al., 2013; Burchfield, 1996). Therefore, the utilization of modelling becomes crucial. Modelling methods are well established to help relevant authorities, academics, engineers and policy makers in Malaysia forecast the future impact of urban development on the quantity and quality of river water in a given basin (Golmohammadi et al., 2014). This may done by assess the current situation before forecast and then evaluation of model were done in order to check the model accuracy.

For watershed problems, the most of physically based hydrologic models from developed countries were not suitable for local use due to the different atmospheric conditions and availability of data (Cambien et al., 2020). Added that the models were too complex to use and not user friendly (Cambien et al., 2020). Thus, a simple GIS interface has been chosen to overcome the lack of integration, limited coordination, and time-intensive execution of the conventional assessment tools (Wang et al. 2019). A few researchers have been successfully improved the SWAT model by integrating with GIS software such as Wang et al. (2019), Bouslihim (2016), Omani et al. (2007), Ridwansyah et al. (2017) and Grey et al. (2014). The results from above mentioned studies show that integration of SWAT-GIS have been evidently produce good performance of model. The improved SWAT-GIS model has better simulation performance and can provide a more suitable way for solving the hydrological cycle (Wang et al. 2019).

Common groundwater recharge rate was assumed to be 6%, 11% and 26% from annual rainfall (Federation of Malaysian Consumers Associations (FOMCA), 2009; Hussin et al., 2020; Waterloo Hydrologic Inc, 2006; Mali & Singh, 2017)) without taking consideration on the land-use and environmental effect. Baung's river was located near Tg Mas Water Treatment Plant that contributed to the Baung's watershed (BW). Such phenomenon already had effect on the recharge rate which will not suite the early assumption of 6 %.

The Water Treatment Plant (WTP) has been developed in Tg. Mas, Kelantan and operated under the management of Syarikat Air Kelantan Sdn Bhd. The Tg. Mas WTP serves as drinking water supplier in Kelantan which involves 11,818 m^3/day of groundwater production capacities as recorded in 2021 (Air Kelantan Sdn Bhd, 2021). Groundwater resource in this area is linked with the Sg. Baung catchment system.

At present, the development in progressively in Kelantan has resulted in increases in the demand for public water supply (Air Kelantan Sdn Bhd, 2015). The production capacities in the WTP Tg. Mas are not able to meet the growing demand and become worse during the drought season due to limited availability of suitable water resources (Air Kelantan Sdn Bhd, 2015). The water treatment plant upgrading project has been proposed to increase the volume of treated water to support the development in Kelantan. Therefore, a project has been proposed to further increase the existing production of groundwater to meet the growing demand from consumers. To determine the new amount of sustainable groundwater production in the area, the groundwater recharge needs to be estimated in order to evaluate the groundwater storage in the study area by considering the factors of land use and climate change in the catchment area (Hussin et al., 2020).

1.3 Objectives

The main objective of this study is to evaluate groundwater recharge rate for sustainable groundwater quantity in aquifer using SWAT model. The specific objectives are:

i. To estimate the hydrogeological properties by combination of geotechnical site investigation and meteorological dataset.

ii. To develop the conceptual and numerical hydrological model using SWAT for Baung's watershed (BW).

iii. To differentiate groundwater recharge rate due to environmental changes such as climate and land-use.

1.4 Scope of Work

The study focused on the assessment of groundwater recharge in basin located in Baung's river in Kelantan. All the data for this study were collected to build the hydrogeological system for the study area which included Digital Elevation Model (DEM), land use map, soil map, soil properties (hydraulic conductivity), river properties (water level and width) and meteorological data (rainfall, temperature relative humidity, solar radiation, and wind speed). The geological structure and hydrogeological properties of the study area were identified based on the well lithology of soil investigation and resistivity survey. Then, hydrogeological model was developed in the study area using SWAT model. The calibration part was not covered in the research due to unavailable of stream flow data in the station. Therefore, the indicators of NSE, R^2, and PBIAS result were analyzed to evaluate the SWAT model performance. The developed model was simulated for 4 different scenarios which were normal rainfall, extreme low rainfall, normal rainfall under future development of land-use and extreme low rainfall under future development of land use. All scenarios in this study have been considered the total amount of rainfall and land-use environment changes. Finally, the result of river discharge obtained were analyzed to determine the groundwater recharge rate for each scenario at the study area.

1.5 Significance of Study

SWAT model is an application that is available to simulate the impact of land-use change based on climate change. The simulation can be done by analysing the catchment area and rainfall of the area. This model can assist to manage water ecosystem and forecasting future events for decision making. The simulation result will be useful for environmental management at Kota Bharu, Kelantan.

1.6 Limitations

i. This project was carried out without any funding supports from UPM. Therefore, alternative sources for the Digital Elevation Model (DEM), land-use map and soil map were considered to address the limitations of this study.

ii. The records of stream flow data was not available in the study area due to unfunctional streamflow station. Therefore, proper model calibration was not performed in this study. The research was limited to evaluate the performance of developed SWAT model.

iii. The stream flow data was only collected within 4 days to evaluate the performance of SWAT model due to limited financial resources in this research.

iv. The Kota Bharu weather station was the only weather station that was close to Baung's Watershed. Since SWAT requires spatially distributed data, this can lead to considerable errors in runoff estimation.

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