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INVESTIGATION OF GROUNDWATER FLOW IN CLAY AQUIFER IN PARIT RAJA CATCHMENT

Mohd Shalahuddin Adnan[1], Norsazwani Mohamad[1], Mohd Adib Muhammad Razi[1], Sabariah Musa[1] and Nurhayati Rosly[2]
[1]Micro Pollutant Research Center, Department of Water and Environment, Faculty of Civil and Environment, Universiti Tun Hussein Onn Malaysia, Parit Raja, Johor, Malaysia
[2]Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, Johor, Malaysia
E-Mail: mohdshalahuddin@gmail.com

ABSTRACT

Groundwater modeling, even as approximations, is a useful investigation tool that groundwater hydrologists may use for a number of applications. The application of modeling is widely used as powerful tool for management or mitigation works. Through modeling, the characterizing the hydrogeological conditions, understanding and simulating groundwater flow patterns as well as groundwater flow directions, assessing groundwater balance, and understanding the hydraulic interaction between river and groundwater can be done. Thus, this study was conducted with the aim to understand the hydrologelogical features and to generate the groundwater flow pattern. The hydrological data such as rainfall, temperature, groundwater level and river flow. While for the geological features, the soil types was determined and derived based on the existing borehole data. Based on the hydrological analyses, the annual rainfall data, evaporation, evapotranspiration and runoff in study area is approximately 2,217 mm, 149.53 mm/a, 320 mm/year and 200mm respectively. The groundwater system that was simulated are confined aquifer where, clay, silt, silty clay and clayed silt are found at 40m depth for downstream area, while, for upstream are consists of gravelly silt, clayed gravel, silty sand, sandy silt and clayed silt area also found in 40 m depth. Through the modeling, the understanding of groundwater flow pattern in area was understand. The groundwater flow is flowing from upstream to downstream area. Lastly, to verify the model results, the model result was compared with the measured data. By referring to root mean square error (RMSE) the error is less than 5% which is 4.98%. The model result from this study was expected to become a helpful tool to assess the impact of changes of the groundwater regime in the environment, to set up/optimize the network monitoring for future sustainable groundwater usage.

Keywords: groundwater flow, hydraulic conductivity, RMSE, clay aquifer, parit raja.

INTRODUCTION

Groundwater is an alternative water resource that widely available. As an alternative for water supply, groundwater has offered several advantages compared to surface water such as higher water quality, protected from chemical and microbial pollutants, less subject to seasonal and perennial fluctuations, and more uniformly spread over large regions than surface water [1,3,8]. Given the demands and desirability of groundwater as a water resource, this valuable resource has been exploited for various purposes either for domestic or industrial uses. However, there are some drawback or the consequences of overuse of groundwater have been widely reported and documented include water level decline, depletion of surface water resources due to groundwater-surface interactions, land subsidence, and saltwater intrusion into coastal aquifers [2,6]

Groundwater becomes the vital resource as drinking water because of the deterioration of quantity and quality of surface water and also due to its attainability (easy to find within this area). Apart from that, it is also cheaper compare to treated surface water. excessive groundwater pumping, and poor sanitation of domestic sewage were the main factors responsible to these problems. In order to keep groundwater is sufficient as a drinking water and/or another purposes, the groundwater management has to be implemented in a proper ways to protect this resource. However, groundwater is very complicated system which made it not really easy to manage. Furthermore, groundwater is situated in subsurface that are well-known for its different properties from one place to another place.

In addition, uncontrolled and not well designed waste management practices have led to chemical and microbial contamination of shallow aquifers on regional scales. Nadiah (2014) has stated that the concentrations of Cl-, NO3-, SO42-, NH4+ were found to be in considerable levels in the groundwater samples particularly near to the landfill sites, likely indicating that groundwater quality is being significantly affected by leachate percolation. While a study by De-Graafl *et al.*, (2015) has mentioned that the uncontrolled groundwater abstraction has affected the geoundwtaer quality close to coastal area. Therefore, effective management of this resource, from both quantity and quality perspectives, is vital to ensure that this valuable resources will not give an adverse impact on our health,, environment, and quality of life.

The growing population at Parit Raja town has significantly increase in the last 10 years and this has triggered an alarm on the availability of water resources for the future. Low number of groundwater study have been conducted in this area and groundwater flow map never been published. It was observed that, this area have high water table, small changes of ground elevation and

the soil types mainly consists of soft clay materials. This condition could be very challenging to map and generate the groundwater flow in this area.

Over the past few decades, researchers have worked extensively on developing closed- form analytical solutions to the adjective-dispersive-reaction equation under a variety of initial and boundary condition [9]. Although these solutions are readily programmable using spreadsheet and can be used to obtain quick solutions under simplified assumptions, the applicability in field-scale scenarios is limited due to the complex geometry and complex reaction kinetics. Therefore, in this study, MODFLOW was utilized to generate the groundwater flow model for Parit Raja. Moreover, the model results will be verified by comparing the water level in measured wells in this area to make sure the map is acceptable and can be used for other purposes.

METHODOLOGY

Study area

The location of study area is situated at Parit Raja town, BatuPahat, Johor. The selection of this area is due to increasing of water demand cause by the substantial population growth in this area. The hydrogeological boundary of this study area was limited by the Sembrong River along the north and trenches along the south area. The assumption on the boundary condition for the eastern and western parts has been made. In general, the total area of this study covered the the area of 50000 m^2.

Data acquisition

In order to model the groundwater flow in the study area, several important data are needed such as hydrology data (rainfall, evaporation, and etc), groundwater water table, boreholes and soil sampling data. The hydrological data obtained from the Department of Irrigation and Drainage Malaysia (DID) and Malaysia Meteorological Department (MMD) for the last 10 years. This data was analayzed to estimate the available amount of water in this basin. Groundwater table measurement was conducted by measuring existing wells around the study area. While for the river measurement, three locations for each boundary were selected which represent upstream, middle and downstream.
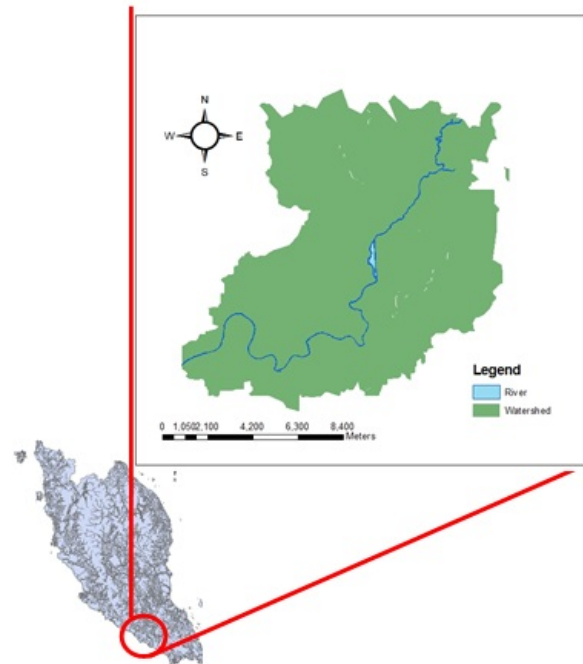

Figure-1. Location of study area.

For the determination of hydraulic conductivity, equation 1 was used to estimate the hydraulic conductivity values because no direct field measurement was conducted to determine this value. To verify the calculated value, the comparison with the measured data was compared to make sure that the value is within the acceptable range.

$$K = \frac{K_1 b_1 + K_2 b_2 + ... + K_n b_n}{b_1 + b_2 + ... + b_3} \tag{1}$$

Where:
K   hydraulic conductivivty for each soil type (m/s)
b   soil thickness (m)

Evapotranspiration is the sum of the water evaporated from the soil surface to atmosphere and that transferred by transpiration from leaves. Evapotranspiration can be limited either by the amount of energy or by the amount of water [5]. To estimate the evapotranspiration ,E_t equation 2 was used

$$E_t = \frac{P}{\left(0.9 + \sqrt{\left(\frac{P}{\sqrt{300 + 25T + 0.005T^3}} \right)^2} \right)} \tag{2}$$

Where:
E_t real evapotranspiration (mm/a)
P   rainfall (mm/a)
T_m annual mean temperature (^{0}C)

While for the calculation of runoff was calculated using empirical formula developed by Sharma Runoff, R_o

$$R_o = \frac{1.511 \, x \, P^{1.44}}{T_m^{1.34} \, x \, A^{0.0613}} \qquad (3)$$

Where:

R_0	runoff (m^3/s)
P	rainfall (mm)
T_m	annual mean temperature (^0C)

For the soil classification, existing borehole data was analyzed. The information on hydrological features was retrieved from Department of Mineral and Geoscience Malaysia. All these data was transformed into GIS database to create required maps. Once the database was developed, all these information will be exported to MODFLOW. MODFLOW has been utilized to generate and produce the groundwater flow model in the study area. The numerical models consist of governing equations, boundary conditions, initial condition. Selection of correct boundary condition is a critical step on groundwater model [4,7,9]. To simulate the real groundwater system, it is necessary to simplify the model by using some assumption. The main assumptions for the study area are; (i) the thickness of groundwater system is assumed range from 30-40 meters, (ii) the material of the groundwater system is mostly fine sand, silty clay, silt, and clay. Hydraulic conductivity is derived from the calculation based on the secondary data, (iii) vertical hydraulic conductivity is equal to horizontal hydraulic conductivity where the aquifer was assumed as isotropy and homogenous aquifer, and (iv) simulated groundwater flow by steady state model.

RESULTS AND DISCUSSIONS

Hydrological setting

The study area is border by river on the right boundary, known as the Sembrong River and Parit Raja trench on the left boundary. The types of river is gaining stream. This river connected with Sg Simpang Kanan at the downstream and ended at the sea.

The meteorological data for this study is provided by Malaysian Meteorological Department. Due to lack of data reason, the nearest meteorological station was choosen to represent the Parit Raja was located at Batu Pahat at 102.9897304 latitude and 1.869936 longitudes. The obtained data were rainfall data, temperature, humidity, radiation, and wind velocity.
Seasonal wind patterns with the local topographic determine the pattern of rainfall in Malaysia. Rainfall pattern in Batu Pahat was influenced by two main season which is dry and wet seasons. Wet season usually occurs between November – Disember while for dry period generally occurs in March – April. The monthly rainfall intensity in study area varies from month to month depend on the raining day as well as the rainfall intensity.

According to annual rainfall from 2004-2013, the annual rainfall data in study area is approximately 2,217 mm. Detailed information about the rainfall records and distribution for the past 10 years in Batu Pahat as show in Table-1.

Table-1. Average of annual rainfall (2004-2013).

Year	Rainfall Intensity	No of Raining Days
	(mm/yr)	
2004	1867.5	287
2005	2224.3	266
2006	2586.3	302
2007	2768.2	326
2008	2070.3	281
2009	1790.4	271
2010	2023.7	291
2011	2357.9	286
2012	2463.4	295
2013	2018.3	295
Average	**2217.0**	290.0

Evaporation

Among all the factors that affect the rate of evaporation, cloudiness and temperature are the two most important factors are interlinked. A cloudy day means less sunshine and thus less solar radiation to lower temperature. Table-2 show the average evaporation rates in Batu Pahat Area for (2004-2013).

Evapotranspiration

Potential evapotranspiration is defined as the amount of water that could be transferred from the soil to the atmosphere given the amount of thermal energy present. The average annual evaporation was calculated by using equation 2 and has found that the average annual evaporation is 149.53 mm/a.

While for the runoff value, equation 3 was utilized to estimate the runoff value. Based on this equation, average annual runoff of the study area is range between 320 mm/year to 380 mm/year. These data will be used as the main input data for modeling data input.

Hydraulic conductivity

The average hydraulic conductivity value for each well log has shown in Table -3. The average hydraulic conductivity value for zone 1 and zone 2 is 1.18E-06 m/s and 3.55E-06 m/s respectively.

Groundwater table

In order to generate the contour map of groundwater water table, 11 observation wells have been measured within the study area by recorded the depth of water. Measurement of water table is wide spread in the

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model area, where the lowest water table was recorded in the downstream part (7.05 m) while the highest water table was recorded in the upstream part (9.09m). From this result, it prove that the groundwater flow from the upstream to the downstream boundary. The depths of groundwater table generally control by the local topography differences.

Table-2. Average evaporation rates (2004-2013).

Year	Evaporation Rates (mm/day)	Evaporation Rates(mm/year)
2004	2.85	1040.25
2005	2.97	1084.05
2006	2.94	1073.1
2007	2.96	1080.4
2008	3.34	1219.1
2009	3.26	1189.9
2010	2.98	1087.7
2011	3.34	1219.1
2012	3.10	1131.5
2013	3.19	1164.35
Total	30.94	11293.1
Average	3.09	1127.85

Table-3. Average hydraulic conductivity value.

Zone	No	Borelog Name	Average Hydraulic Conductivity (m/s)	Average (m/s)
2	1	UTHM BH1	5.86E-07	1.18E-06
	2	UTHM BH2	5.14E-07	
	3	UTHM BH6	1.38E-06	
	4	UTHM BH3	1.78E-06	
	5	UTHM BH4	1.72E-06	
	6	UTHM BH5	1.11E-06	
1	7	MASJID 1	3.01E-06	3.55E-06
	8	MASJID 1	2.32E-06	
	9	MASJID 1	2.62E-06	

River measurement

Measurement of river parameter is indispensable parameter for simulating the boundary conditions in modeling process. In the study area, there are two main rivers, which are the Sembrong River and the Parit Raja Trench that was assigned as a river boundary. In the modeling process, it is required that the river parameter such as river stage, river bottom, riverbed thickness, depth of water, and the material of riverbed to define the boundary accurately. By knowing the input parameter, field work can be well organized. Measurement was conducted at the Sembrong River and Parit Raja Trench. Each river has been measured at three different places at the upstream boundary, middle, and downstream

boundary. Table-4 shows the result of river measurement that has been conducted.

Table-4. River boundary conditions.

River		Coordinate		River Stage (m)	Riverbed Bottom (m)	River Width (m)
		X	Y			
Sembrong River	Upstream	6699.2	4547.1	7.1	3.1	18
	Middle	5380.2	4419.8	7	3.0	51
	Downstream	4616.5	4755.4	6.8	2.9	32
Parit Raja Trenches	Upstream	8666.1	3552.1	7	3.9	12.6
	Middle	5507.4	2036.4	7.1	4.1	18.0
	Downstream	2487.6	971.9	6.9	4.0	13.8

Geological setting

Basically, the study area is located in the flat plain area with puddles at the surface. Geological features around Parit Raja area is a boundary formation of Alluvium Queternary which is consists of marine and continental deposits that usually clay, silt, sand peat with minor gravel. The lithology alluvium deposit consists of river deposit, marine deposit, and delta deposit which overlay and interfingering each other's [10].

The process of sedimentation that continuously happened will caused the border between the sea and land move further to the sea. This phenomenon can be proved by looking at the drilling work data that have been reported by Maju Teknik Kota Sdn Bhd, based on the drilling results it shows that there are existence chip of shell at depth 3 meter until 10 meter. According to [10], it is predicted that UTHM and its surrounding area previously was a muddy and sandy coastal area, and the water containing high Calcium and Chloride due to ancient salt water intrusion at quaternary era and effects of karsts under the land surface, respectively. Granite rock (red) in Batu Pahat and seal rock (green) in Air Hitam dominates almost areas of Batu Pahat, Parit Sulong, and Yong Peng as well as in Parit Raja.

Based on the previous borelog data from 9 existing borehole, type of soils and hydrogeological fence diagram of study area was identified and developed. At the downstream area, clay, silt, silty clay and clayed silt are found at 40m depth, however, for upstream area, gravelly silt, clayed gravel, silty sand, sandy silt and clayed silt area also found in 40 m depth. Figure-2 and Figure-3 shows the hydrogeological fence diagram of study area for left boundary-right boundary and upstream boundary –downstream boundary and respectively.
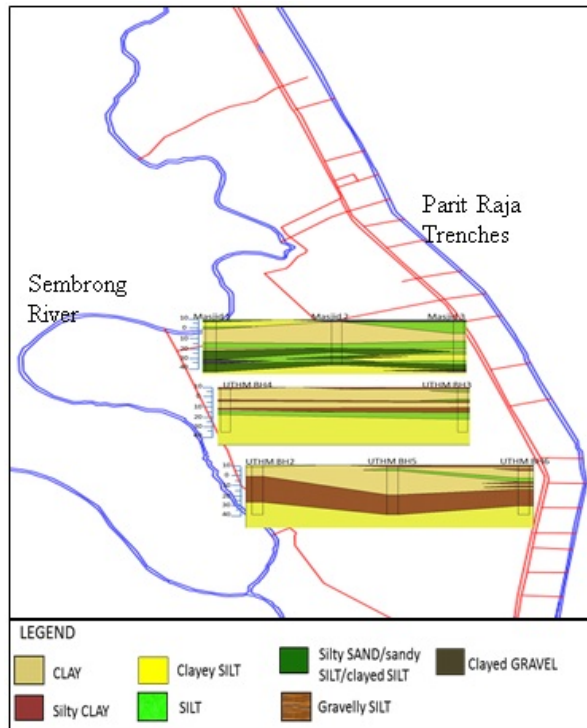
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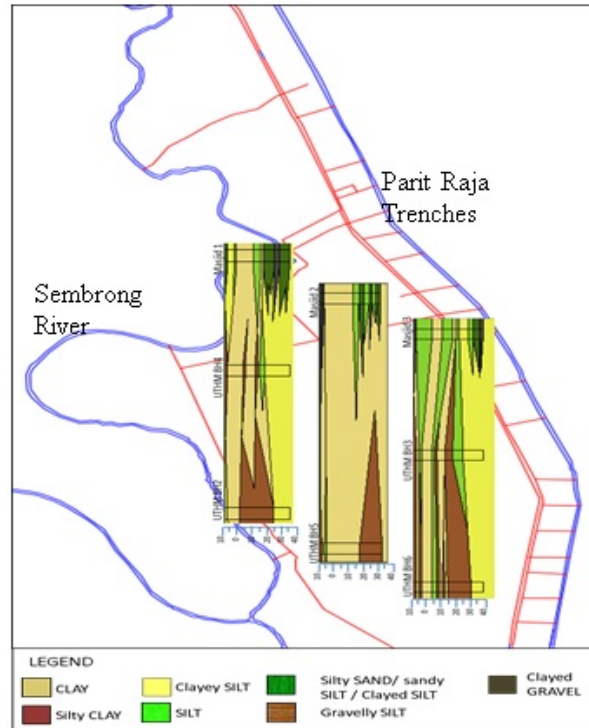**Figure-2.** Hydrogeological fence diagram of study area (left boundary and right boundary).

Figure-3. Hydrogeological fence diagram of study area (upstream boundary –downstream boundary).

On the hand, the elevation in this study area are varies generally flat from 2 meter -15 meter from the sea level with the average slope and maximum inclined slope 1.0^0 until -1.0^0 and 5.2^0 and -3.9^0 respectively.

In this study there is two boundary was assign which is river head boundary and constant head boundary. River head boundary are along Sembrong River and Parit Raja Trench. For the constant head boundary are along upstream and downstream boundary. Figure-4 show boundary condition of study area.

Groundwater flow model

The groundwater flow model as shown in Figure-6. From the model result, it shows that the groundwater flow pattern in study area is flowing from the upstream boundary to downstream boundary. Besides, from the model we can see both of river Boundary which are the Sembrong River and Parit Raja Trench are experiencing gaining stream. In addition, the contour line at upstream part closer than at the downstream part indicates that the velocity at the south side is faster than the velocity at the north. According the Darcy's Law, v=ki, when the area have high velocity it will also have a high value of hydraulic conductivity, as the result of hydraulic conductivity which calculated earlier, the values of conductivity from the south heading to the north is decreases.
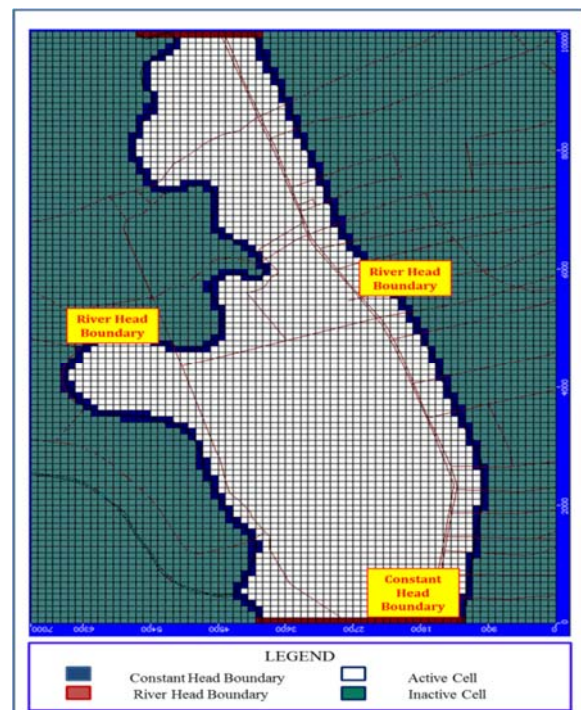

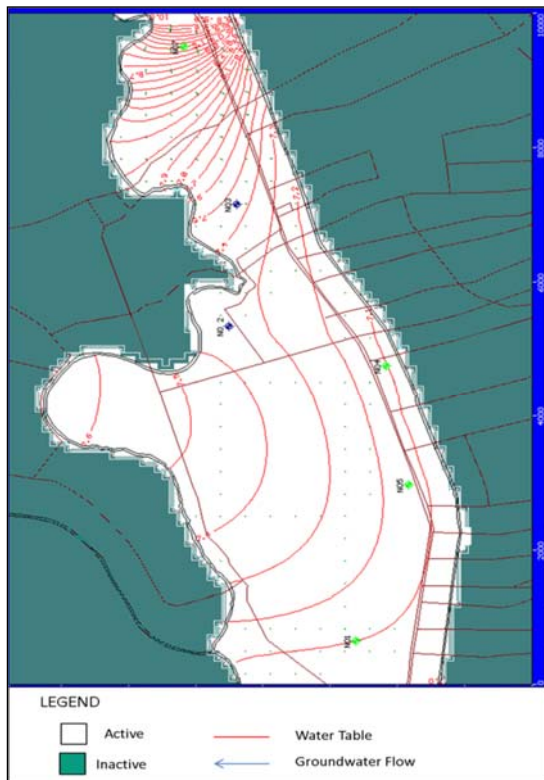**Figure-4.** The boundary condition of study area.

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Figure-5. Groundwater flow pattern.

Figure-6. Calculated versus measured head.

To verify the result from the model, calibration process was carried out by comparing the water level results from model and measured. Calibration is the process by which the independent variables parameters of a model are adjusted, within realistic limits, to produce the best match between simulated and measured data. The trial and error is one of the processes to determine which parameter is the most sensitive. The most sensitive parameter which controls the model result is the. Besides, only value of hydraulic conductivity will be change due to the ambiguities of hydraulic conductivity value since the value was obtained from the calculation not from the field measurement at the field. However, the value chosen still within the limit of hydraulic conductivity value at the study area which is $1x10^{-1} – 1x10^{-5}$. After some calibration that have been done, the best hydraulic conductivity chosen is $1.5x10^{-4}$ ms^{-1} and $3.6x10^{-4}$ms^{-1} for zone 1 and zone 2 respectively.

The acceptability of a calibration process can be assessed by looking at the scatter diagram show in Figure-6. This scatter diagram are produce from output of the model. This graphical representation of observed head and calculated heads. The indication to know whether the result has a high quality or not, all of the points falling on the 45°straight line which means that the measurement values is more or less same with the calculated value. The less scatter point in the graph shows a high quality of the result.
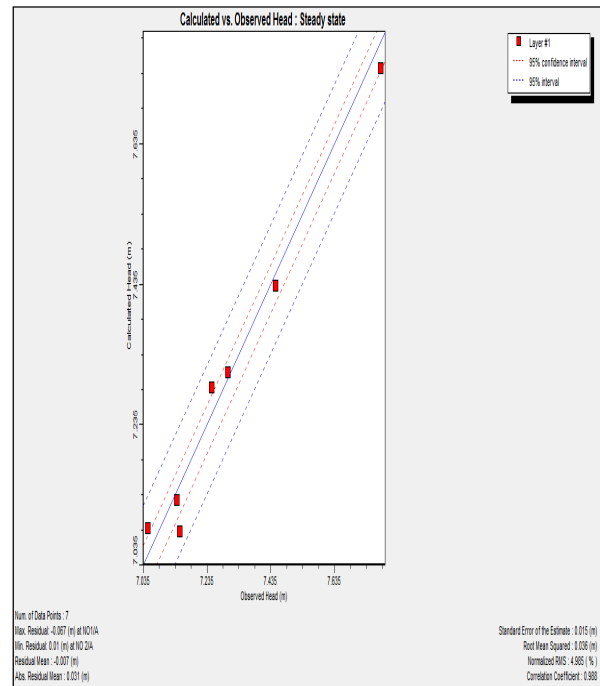
Besides, the quality of the result can be shows by error that has been shown at the footer of the scatter graph. Root mean square error (RMSE) and mean absolute error (MAE) indicate the variance between the observed and calculated values. The mean absolute error is 0.031 meter indicates the differences between the hydraulic head of the model with the hydraulic head of measurement at field. For Root mean square error value is 4.985 % of error. According to Spitz and Moreno (1996) has suggested a criterion of about 5% for the scaled RMS to be regarded as a well calibrated model.

CONCLUSIONS

In this paper, the application of computer simulation to generate the groundwater flow was discussed. Several important data are needed in order to run the simulation such as precipitation, temperature, groundwater water table, hydraulic conductivity, and related maps. Based on the simulated result, it shows that the groundwater is flowing from north to south. The calibration process was done to verify the confidence level of model by comparing the model with measured data. Based on the calibration process, the RMS error is less than 5% which is 4.985%. This result could be a useful tool for the related agencies or department to conduct the mitigation works.

ACKNOWLEDGEMENTS

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