

Groundwater Flow Modeling in the Malioboro, Yogyakarta, Indonesia

Alwan Satapona*, Doni Prakasa Eka Putra, and Heru Hendrayana

Department of Geological Engineering, Faculty of Engineering, Gadjah Mada University, Yogyakarta, Indonesia

ABSTRACT. Malioboro is a famous tourism area in Yogyakarta City, in which there are many hotels and increases every years and this follows by the increasing needs of fresh water taken from underlying groundwater. The decreasing of groundwater table become a great issue on this area, therefore the objective of the research is to predict groundwater table change in the next 10 years due to increase abstraction of groundwater. To answer the mentioned objectives, field observation of dug wells and collection of secondary data of log bores also calculation of recharge and water abstraction are used to understand and build the conceptual model of local groundwater system. The prediction is done by conducting simulation on a numerical groundwater model by using MODFLOW. The local groundwater system consists of two aquifer layers; upper aquifer and lower aquifer which separated incompletely by clay layer. Simulation is conducting by distributing the groundwater pumping for domestic and non-domestic utilization by dug wells in the upper aquifer, whereas deep wells non-domestic utilization are applied only in the lower aquifer. Simulations are conducted twice for the recent day and the next ten years prediction of groundwater abstraction. In the case of groundwater abstraction in the next ten years, dug wells abstraction and deep wells pumping are setting to 4727 m³/day and 1648 m³/day, respectively. The groundwater pumping rates is representing increase of groundwater withdrawal of users in the range only between 0.2–1.2 % per year compare to the recent condition. The simulation reveals change occur on groundwater table depth and pattern. In average, the groundwater table will decrease of about 0.25 meter.

Keywords: Groundwater flow model · Groundwater table · Malioboro · Yogyakarta · Indonesia.

1 INTRODUCTION

Malioboro area is the most popular area in the city of Yogyakarta (see Figure 1). Around the area there are several historical objects such as Tugu Yogyakarta, Tugu Railway Station, Gedung Agung, Beringharjo Market, Vredeburg Fort, and Monumen Serangan Oemoem 1 Maret which makes Malioboro area becomes one of the centers for tourism and lodging purposes (Sholihah, 2005; Sunaryo *et al.*, 2013). Actually nowadays, the tourism area includes Malioboro and its surrounding area, which is about 13.45 km² in wide and includes several sub-districts,

namely Jetis, Tegalrejo, Gedongtengen, Danurejan, Ngampilan, Kraton, Gondomanan, Mergansan, and part of Depok, Pakualaman, Wirobrajan and Mantrijeron.

Hydrogeologically, Malioboro is located in the Yogyakarta-Sleman Groundwater Basin. According to MacDonald & Partners (1984), this groundwater basin developed by Young Merapi deposits which is divided into Sleman and Yogyakarta Formation. The relationship between the Yogyakarta Formation and Sleman Formation in the field is unclear, but both of formations are differentiated by grain size, in which Sleman Formation is rougher than the Yogyakarta Formation (MacDonald & Partners, 1984; Putra & Indrawan, 2014). This groundwater system classified as productive aquifer sys-

*Corresponding author: A. SATAPONA, Department of Geological Engineering, Gadjah Mada University. Jl. Grafika 2 Yogyakarta, Indonesia. E-mail: alwansatapona@gmail.com

tem with shallow groundwater table condition and become the source of clean water supply on this region including in the Malioboro area, Yogyakarta City.

To accommodate the needs of tourism, 173 hotels are available around Malioboro and its surrounding area, in which 11 hotels are star hotel. Dinas Pariwisata DIY (2016) reports that the total number of tourists who comes and uses the accommodation services in both star and non-star hotels increases over the years. This increase is expected to be proportional to groundwater withdrawal as Local Waterworks (PDAM) can not afford to meets the community's water needs. Putra & Indrawan (2014) stated that the Yogyakarta City is a region with a high degree of susceptibility to the over-exploitation. Therefore, excessive pumping can threaten the groundwater condition in the study area. Previous regional groundwater flow model conducted by Putra *et al.* (2013), reveals that with the pumping rate of totally 125000 m³/day in the whole Yogyakarta City area, will cause groundwater table to be decrease to about 3 m.

Meanwhile, the study from Dinas PUP-ESDMDIY (2012) shows that the average of groundwater level in Yogyakarta City is already decrease to about 0.3 m/year. Therefore, it is important to predict the effect of increasing groundwater exploitation in the Malioboro-Yogyakarta City, Indonesia, urgently in the local scale (Figure 1). To do this, a numerical groundwater modeling will be as an effective method as mentioned by Spitz & Moreno (1996) and Anderson & Woessner (1992), and the results can serve to answer question from community of what is the impact of deep groundwater pumping activities to shallow groundwater level in Malioboro. And the result can be as the basis for decision making in groundwater management for the famous tourism area in the Yogyakarta City.

2 THEORETICAL BACKGROUND

Numerical groundwater flow modeling is a good method for groundwater management and for predicting the impact of a treatment on groundwater systems in certain areas (Anderson & Woessner, 1992). Numerical flow modeling is a suitable modeling method to simulate

3-dimensional models, and complex and heterogeneous aquifer conditions (Spitz & Moreno, 1996). The numerical model is a combination of mathematical descriptions, numerical computer program and their application in groundwater problems (Spitz & Moreno, 1996). The numerical computer program will solves algebraic equations that resulting through the partial derivative equations approach of the governing equation, boundary conditions, and the initial conditions that make up the mathematical model.

According to Anderson & Woessner (1992), groundwater flow equation is a mathematically derived result of a combination of water equilibrium equations and Darcy's Law. The properties of pore media in nature are presented in a small square box called Representative Elementary Volume (REV), where the volume is equal to $\Delta x \Delta y \Delta z$ (see Figure 2). According to Todd & Mays (2005) to formulate the mathematical equations of groundwater flow in the system, the REV is assumed to be homogeneous and isotropic, the flow occurs only in one direction through the REV, and the fluid movement motion is defined in the parallel flow parallel components of the three major axes. Mathematically derived combination of water equilibrium equations and Darcy's Law, yields the following 3-dimensional groundwater equation (Equation 1).

$$\frac{\partial}{\partial x} \left(K_x \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_y \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left(K_z \frac{\partial h}{\partial z} \right) = S_s \frac{\Delta h}{\Delta t} - R^* \quad (1)$$

where K_x , K_y and K_z are hydraulic conductivity components, x , y and z are cartesian coordinates, S_s is specific storage, and R^* is groundwater recharge. The equation above by the computer program is solved by using numerical solutions. The commonly numerical solution is finite difference method, because it is easier to understand and the required input data is also less than others. The finite difference method normally solves algebra equations by combining matrix and iteration techniques (Anderson & Woessner, 1992). One of the famous finite difference numerical groundwater model which widely used is MODFLOW. Modflow is a computer code that simulates one-, two-, or three-dimensional groundwater flow using a fi-

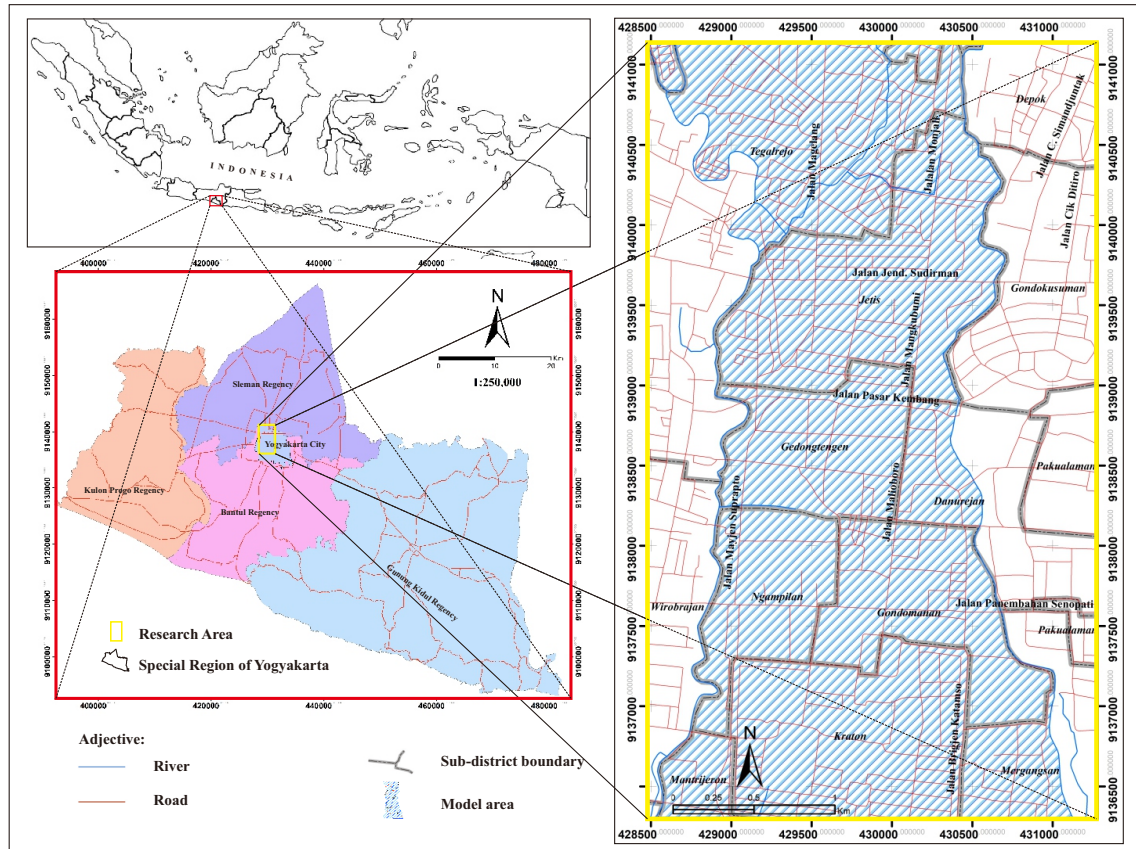


Figure 1. Map of research area.

nite difference solution of the model formulation, can simulate steady and nonsteady flow in an irregularly shaped flow system in which aquifer layers which can be confined, unconfined or combination of confined and unconfined (Todd & Mays, 2005). Flow from external stresses, such as flow to wells, areal recharge, evapotranspiration, flow to drains and flow to river beds, can be simulated. Modflow uses block-centered finite-difference grid type (Fetter, 2001).

3 METHODOLOGY

In order to achieve the objectives of the research, field observation and collection of secondary data were conducted. Field observation which conducted are measurement of the water table of shallow/upper aquifer in which 214 dug wells were observed twice during wet dan dry season of 2017, and measurement the river stages including observation on the type and thickness of river sediments on the Code and Winongo river. Collection of secondary data were conducted to get the information of deep/lower aquifer, climatology and ground-

water utilization in the study area. There are 11 bore holes information with the depth up to 140 m can be collected from the PUP-ESDM DIY Office, but climatological data is taken from BPS DIY office. Groundwater utilization data of non domestic usage was also got from PUP-ESDM Office, but groundwater utilization of domestic use was only estimated from number of population.

Measurement of water table from dug wells were analysed to reveals water table map of the upper aquifer system, and piezometric level of lower aquifer were got from bore holes data. The hydrostratigraphy and aquifer characteristics were also analysed from the bore holes data. Groundwater recharge were estimated based on water fluctuation method (Healy & Cook, 2002) as the study area is urban area. All of these information then compile together to built the conceptual model and input for the groundwater modeling. The scheme of groundwater flow modeling stage that conducted in this study is as seen in Figure 3.

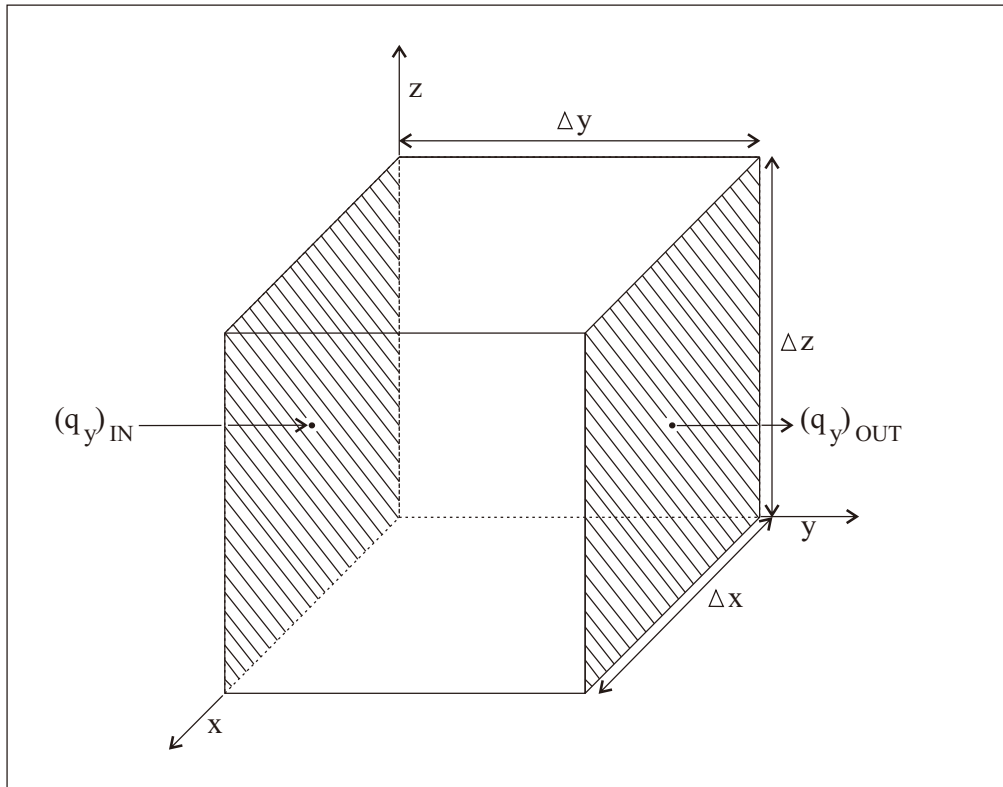


Figure 2. Representative Elementary Volume (REV) (Anderson & Woessner, 1992).

4 RESULTS AND DISCUSSION

4.1 Groundwater natural system

Result of dug wells measurement show the groundwater table elevation is at 126 masl the north boundaries of the study area while in the southern boundaries, the groundwater table elevation is only about 88 masl. The map of shallow groundwater elevation and flow pattern is shown on [Figure 4](#). On this figure, shallow groundwater flows from north to south and near to the two main rivers, the groundwater flows into the rivers built gaining stream system and this allows several seepages occur in the river walls. On the other side, information from deep wells found that the piezometric level ranges between 186 and 86 masl from north boundaries to the southern boundaries of study area. Due to the sparse and limitation of data, it is not possible to draw the piezometric level map, and it is assumed that this piezometric level is change linearly from north to south.

Based on the log bore data of several deep pumping wells with the depth up to 140 m, stratigraphical correlation on the study area can be built. In general, research area is composed by sediment layers of sand, clay and clayey sand deposit (see [Figure 5](#)). The position of

sediment layers can be interpreted as follows: sand unit is located in the elevation ± 39 to 64 masl, clay unit ± 34 to 42 masl with thickness range from 2 to 8 m and clayey sand unit is located at elevation ± -10 to -20 masl, and clay layer at elevation less than -20 masl. Between sand layer and clayey sand unit, there are layer of incomplete clay allowing hydraulic connection between those lithological unit. The sand unit built a shallow phreatic groundwater system called as upper aquifer system, whereas the clayey sand unit developed a lower aquifer system which classify as semi-unconfined aquifer system.

According to previous research (Putra, 2003, and Putra *et al.*, 2013) with new pumping test data of bore holes, the upper aquifer layer has hydraulic conductivity value of about 7.8 to 90 m/day. Meanwhile, hydraulic conductivity of the lower aquifer is about 1.1 m/day. The hydraulic conductivity of clay units that bounds both of aquifers are given 1×10^{-4} m/day. The porosity of the upper aquifer system of the research area is 0.3, a specific yield value is 0.2. Whereas the coefficient storage of the lower aquifer is 0.02.

Climatological data of the study area is eval-

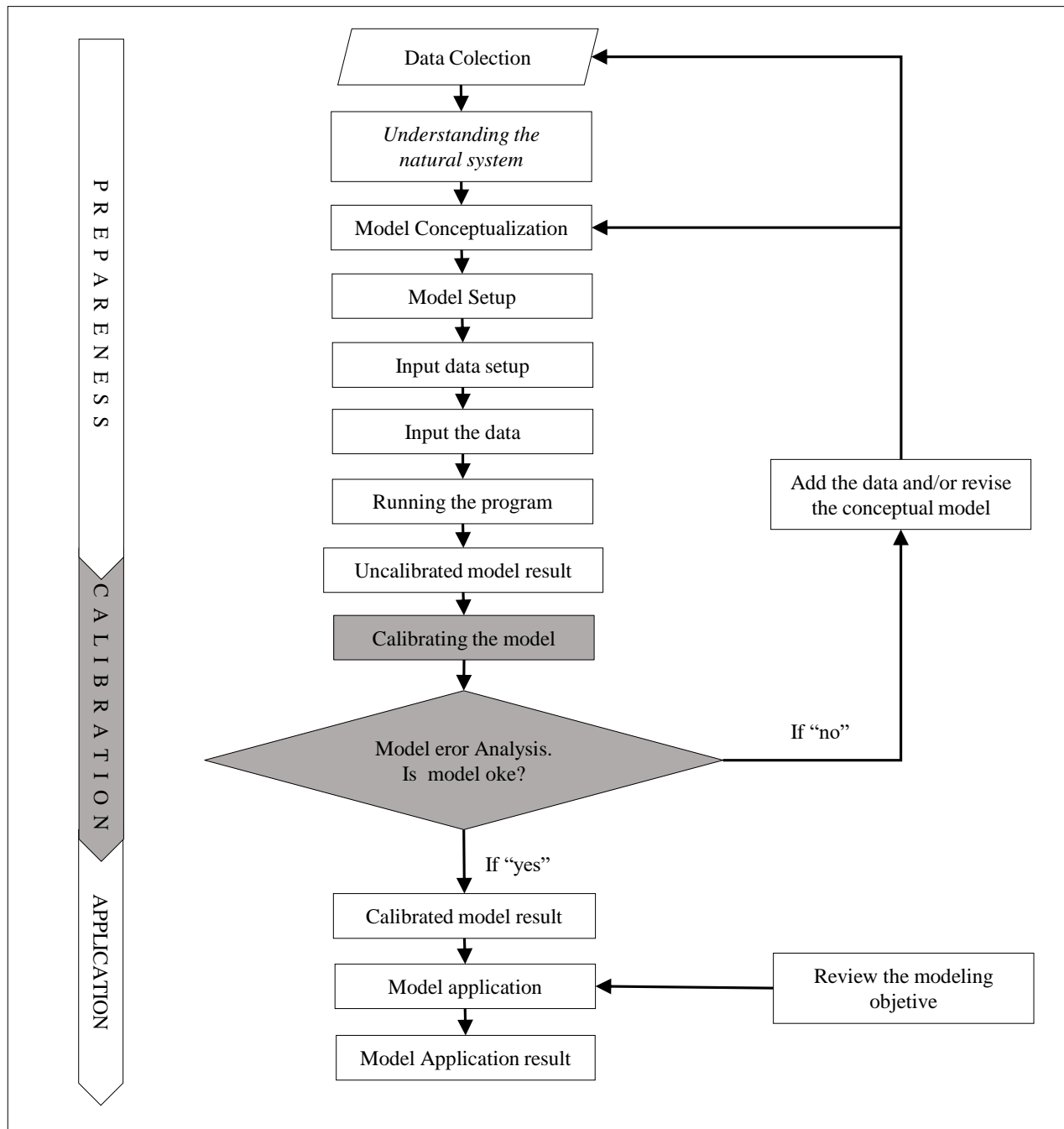


Figure 3. The scheme of groundwater flow modeling stages.

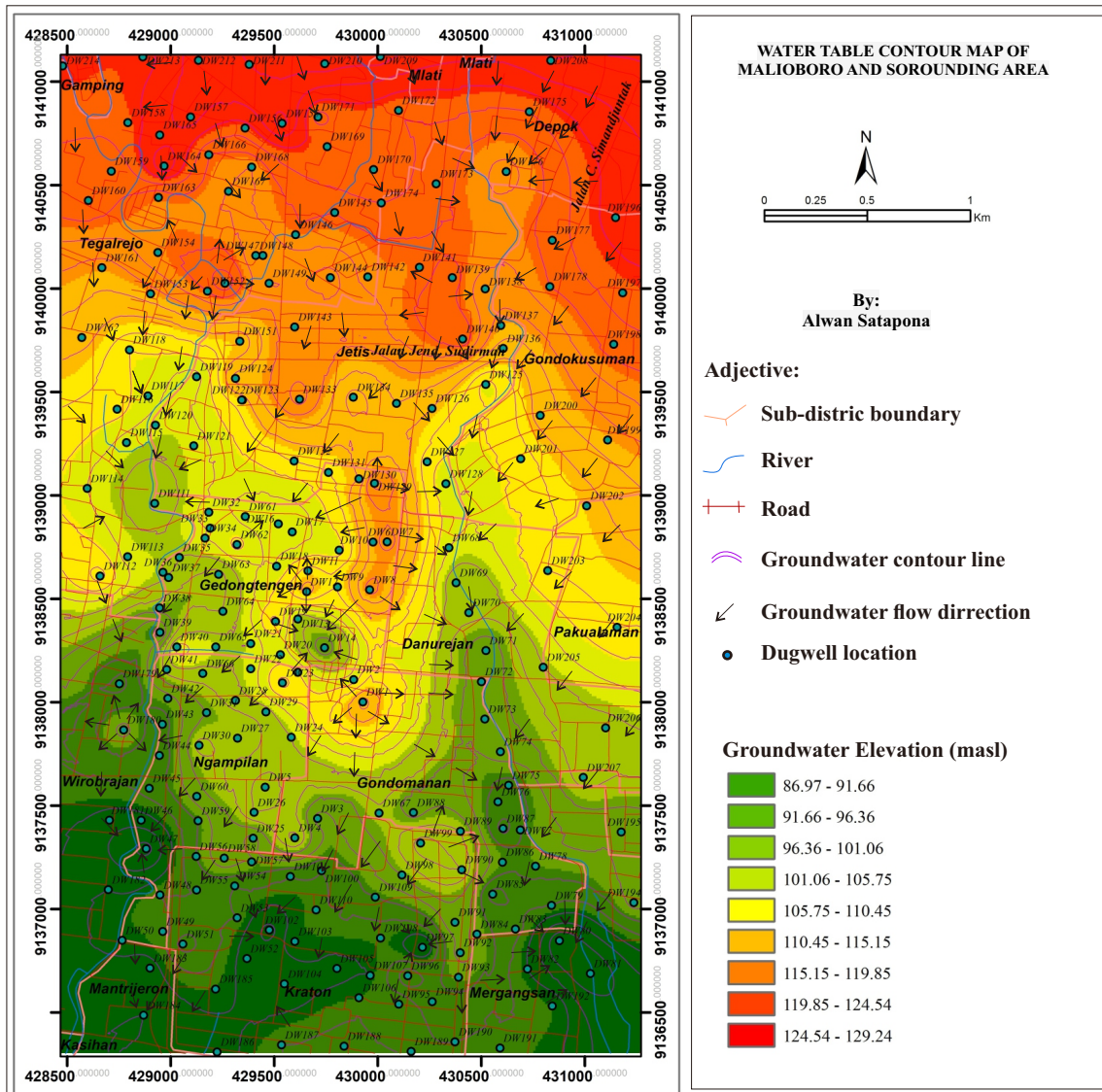


Figure 4. The water table map of Malioboro-Yogyakarta, Indonesia.

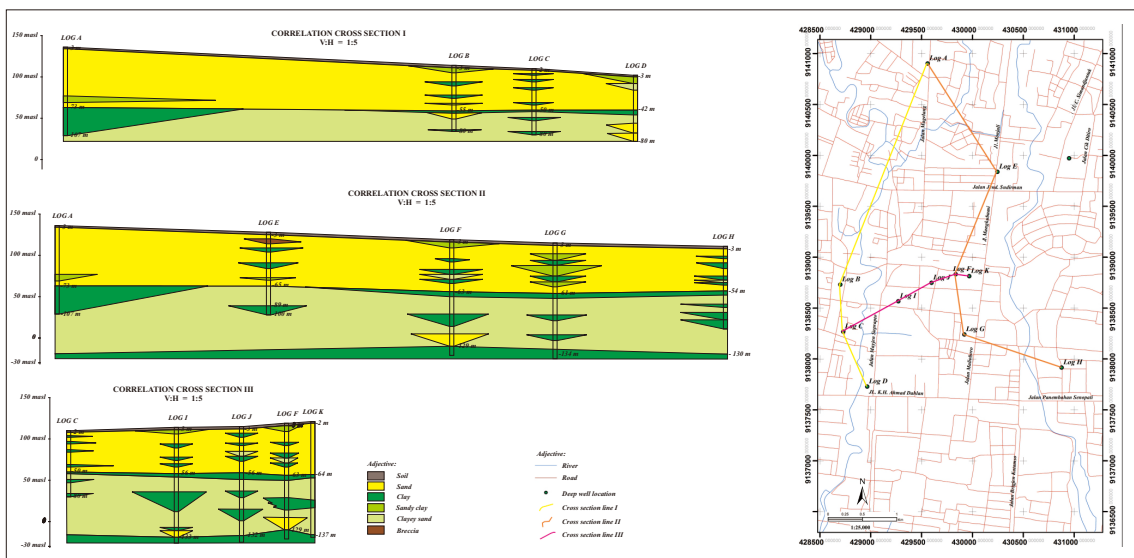


Figure 5. The layer of sediments occurrence in the study area.

uated from recorded climatological data from 2010 to 2016. The annual precipitation in the study area is about 2558 mm/year, while the mean temperature of the study area in that period is 28.2 °C. Calculation of recharge on this dominated urban business and tourism area shall be consider not only direct recharge from rainfall but also urban recharge. Therefore, water table fluctuation method (Healy & Cook, 2002) is used to estimate the groundwater recharge. Based on the field observation during dry and wet season of 2017, the annual change of water level in the study area ranges between 0.41 to 2.68 m. By applying water table fluctuation method and value of specific yield 0.2, the groundwater recharge on the study area will be between 82 to 536 mm/year, or in average about 300 mm/year.

Groundwater use in the study area can be differentiated into three categories; domestic use (dug well source), non-domestic use with dug well source and non-domestic use with deep well source. The existing domestic use in the study area is about 3429 m³/day. This value is higher compare to non-domestic use of groundwater in the study area, which found that 850 m³/day of groundwater is pumping from shallow groundwater aquifer and 1615 m³/day of water is pumping from the deep wells.

4.2 Conceptual model

Based on the groundwater condition, the model conceptual of natural of natural system can be built (Figure 6). Aquifer system in the study area can be simplify into two homogeneous aquifer system (upper and lower aquifer). Upper Aquifer composed by sand unit and Lower Aquifer composed by clayey sand unit. Both of aquifer layers are separated incompletely by clay layers that is impermeable and forms aquifer windows. Boundaries of the model will be constant head boundaries in the north and south of the study area, and on the east also west, drain boundaries is applied representing gaining stream system of Code and Winongo rivers. The drain boundaries were only apply on the upper aquifer similar to groundwater recharge.

4.3 Model setup

For modeling purposes, the study area is divided into three area; target area, model area

and uncalculated area. In general, the study area were descritized into 50×50 meters grid size, and yields 56 columns and 96 rows as seen on Figure 7. The orientation of the grid is adjusted to the direction of groundwater flow in the study area of north to south direction. Special for the target area, smaller grid size of 25×25 meters were applied.

The boundaries in the north are inputted by constant groundwater table elevation and piesometric level of 123 to 126 masl for the Upper Aquifer and 128 masl for the Lower Aquifer. While the boundaries of constant head in the south are about 88–94 masl for the Upper Aquifer and 86 masl for the Lower Aquifer. Code and Winongo Rivers are inputted as drain boundaries, with the value of conductance drain is inputted by 3 (1/day) representing the type of sediments in the river. Characteristic of aquifer, recharge and groundwater pumping are inputted similar as explained in the groundwater natural system.

4.4 Model result

After inputting data and running MODFLOW program, the groundwater flow model results uncalibrated groundwater flow model. Uncalibrated model result can be seen in Figure 8a. On this figure, it is clearly seen the water table of the model is lower than the field measurement data. The value of normalized RMS of the uncalibrated model is about 14.5%. The calibration process on this model is conducted by changing input parameter of aquifer characteristics and recharge value. During the calibration process, it can be identify that the enlargement scenario of hydraulic conductivity value reveals smallest error value. After adjusting the hydraulic conductivity value to be about 10 times larger from initial model with also increasing of recharge value on some model areas to about 2 times from initial model, the model show smaller error with normalized RMS value of only 6.2 %. The groundwater table contours between model results and observation results is also match (see Figure 8b).

4.5 Model application

As mentioned in the background, the increasing number of hotels built and exploit the groundwater in the Malioboro from lower aquifer increase the fear of the community that the water

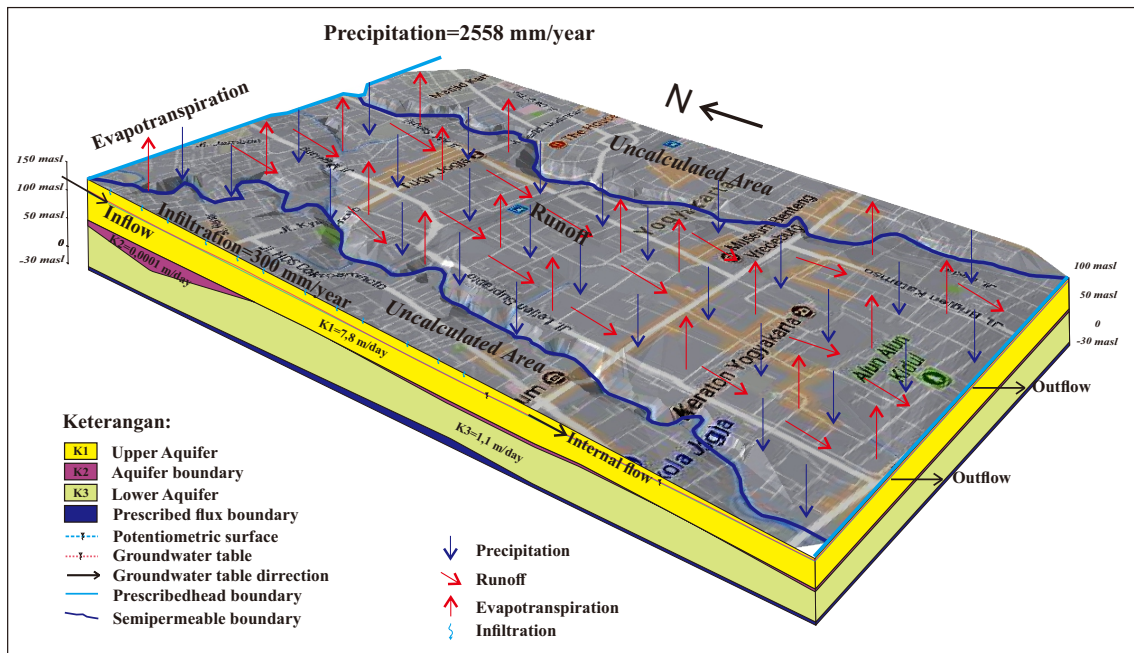


Figure 6. The hydrogeological conceptual model of Malioboro-Yogyakarta.

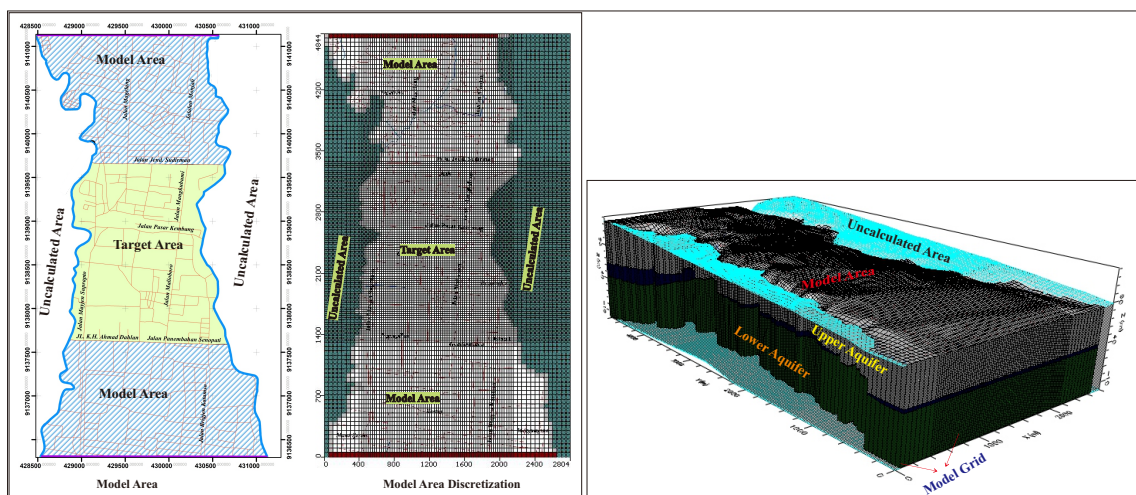


Figure 7. Discretisation of model area.

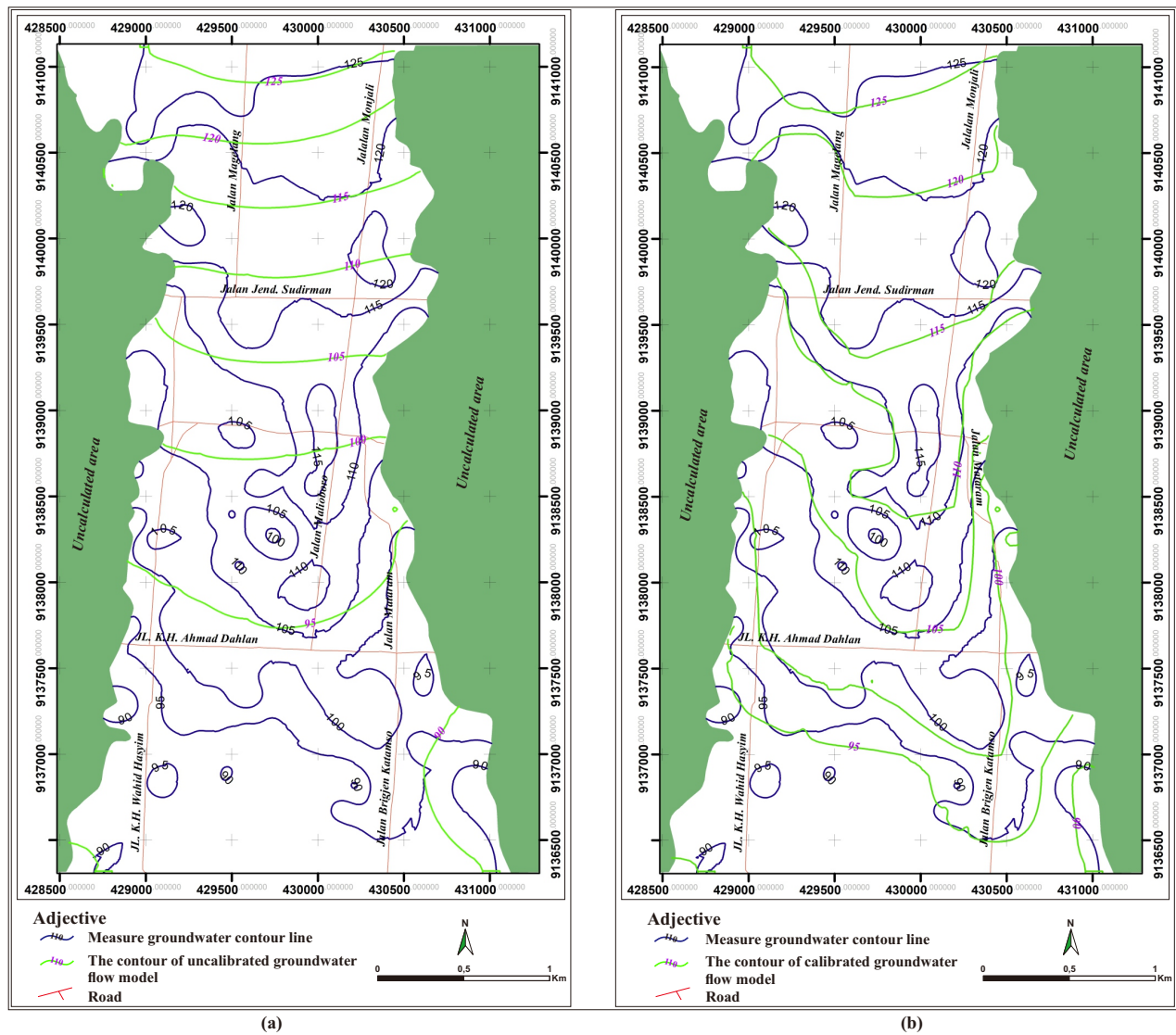


Figure 8. (a) uncalibrated groundwater flow model and (b) calibrated groundwater flow model.

table on their dug wells will be affected and may decrease significantly, therefore the calibrated model is used to simulate whether those arguments can occur or not. Simulation on the effect of increasing groundwater abstraction is conducted by changing the initial abstraction of groundwater to expected value of abstraction for the next ten years. The increasing groundwater pumping is assumed to be linear with the growth rate of population and tourists on this area. Based on BPS DIY (2017), the population growth in Malioboro areas is about 1.22%. While the growth rate of tourists who use hotel accommodation is about 0.20% for star hotel and 0.15% for non-star hotel. Table 1 shows the projected pumping discharge for the next ten years. From this table, it is recognised that the most increasing groundwater withdrawal for the next ten years will be due to domestic use (dug wells) of about 435 m³/day higher than recent time.

The simulation results of model application scenarios can be seen on the groundwater contour map of the model application (see Figure 9). Based on Figure 9, by applying such a scenario, the groundwater table is changed or affected by the increasing of withdrawal activities. Areas suffering great change mainly occur around the main road of Malioboro up to 1.2 m. Meanwhile, the decreasing value of groundwater table ranges between 0.1–0.3 m, and the average groundwater table is decreased by about 0.25 m in the whole study area. This condition shows that even with only a small increasing rate of groundwater pumping on this area, the degradation of water table will occur. As the most significant increase of groundwater withdrawal due to domestic use, this scenario can be avoided if the plan of government of Yogyakarta Special Region to implement 100% piping water system on this area can be executed as soon as possible.

5 CONCLUSION

From the results of this study, it can be concluded that the hydraulic conductivity of the aquifer in the study area is higher about 10 times to the regional hydraulic characteristics of the Merapi aquifer system. Another side, the recharge in the densely populated area such as the study area is more or less still occurring and may be

higher due to urban recharge conditions. Simulation on the effect of increasing groundwater abstraction for the next 10 years reveals that the water table in the upper aquifer will decrease in average of about 0.25 m in average, but may be up to 1.2 m in the main road of Malioboro. It should be borne in mind that this simulation is conducted with the assumption that the rate of groundwater withdrawal is in accordance with the increase of population, business and tourist growth rate.

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Table 1. Projected pumping scenarios for the next 10 years.

The Groundwater Use		The rate (m ³ /day)		The rate of growth (%)
		Before	After Projection	
Domestic use		3429	3864	1.22
Non-domestic Use	Dug wells	850	863	0.15
	Deep wells	1616	1648	0.2

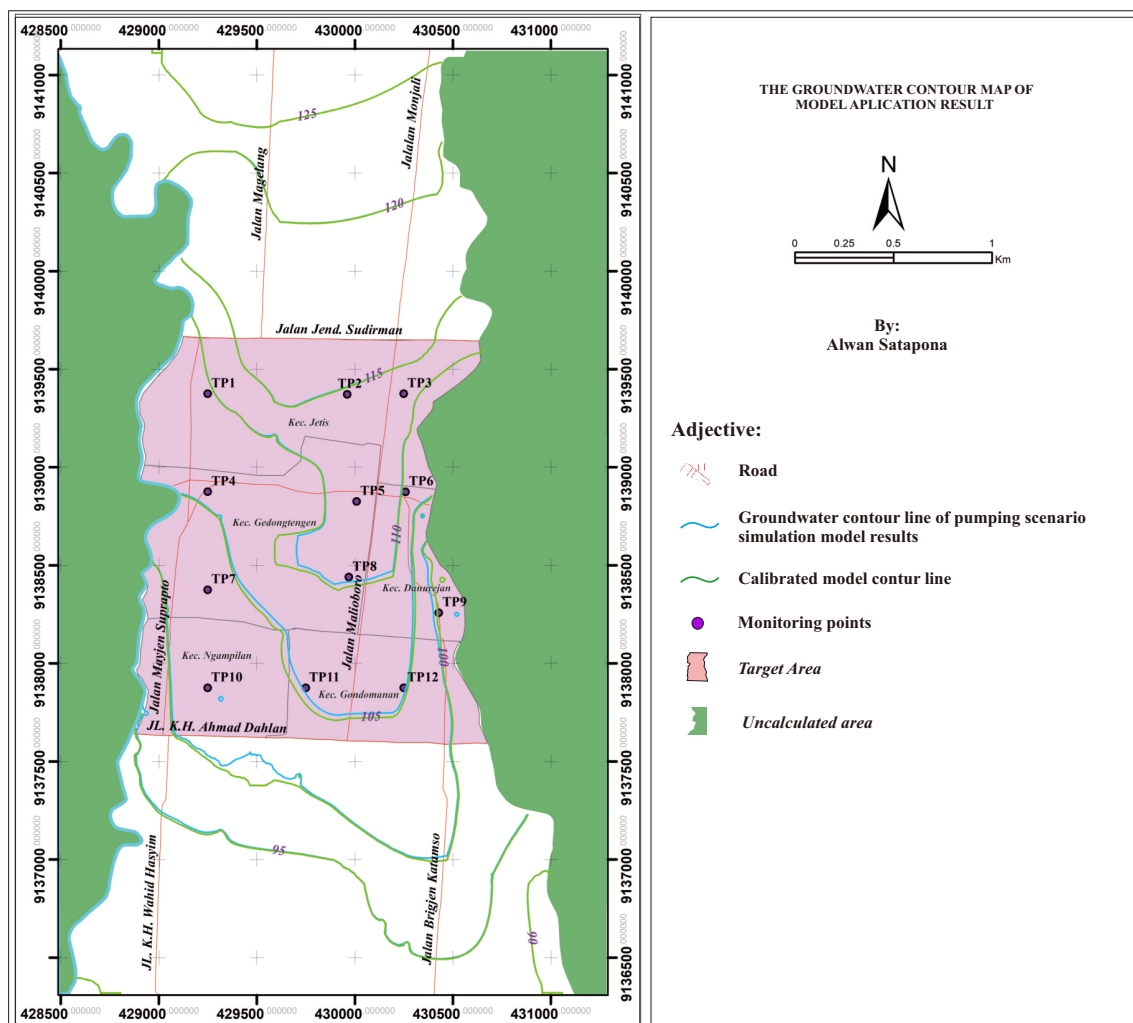


Figure 9. The map shows the changes of groundwater contour pattern to be happened in target area.

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