Research Article

Impact assessment of apartment building foundation to Terban spring discharge, Yogyakarta City

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Abstract: The development growth of hotel and apartment in Yogyakarta city is considered to have an impact on groundwater, especially springs located along the river across Yogyakarta city. Most of the foundations of hotels and apartments are below the groundwater level. Therefore, this study aimed to predict the impact of apartment building foundations on Terban spring discharge in Yogyakarta city. Method of impact prediction was conducted by groundwater modeling approach before and after the apartment is built. Visual Modflow 3.1 software was used to develop groundwater modeling in the research area with input parameters including rock types and layers, permeability value of each rock, recharge, model boundary, groundwater level and apartment foundation design. The simulation results show that the impact of apartment foundations on the Terban spring water discharge causing decreased by 4.12% or 0.027 litres/second. Although the amount of spring discharge is relatively small, therefore it is necessary for groundwater conservation to keep the spring discharge stable by developing recharge wells.

Keywords: apartment foundation, groundwater model, spring discharge, visual modflow

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Introduction

Indonesia’s economic conditions have improved in the last decade. It also gives influence on the development of Yogyakarta city, especially in the tourism facilities such as hotel and apartment. This condition was supported by the increasing amount of hotel and apartment, which in the last five years has been very rapid. According to statistics data, in 2012 there were 36 star-rated hotels, but at the end of 2017, the number jumped to 96 (Yogyakarta Special Region Tourism Office, 2017). The growing of hotels and apartments have the possibility to give an impact to groundwater, especially in quantity because almost all hotel and apartment foundations reached below groundwater level. There are many rivers in Yogyakarta city, one of them is Code river. This river is located in the middle of Yogyakarta city and many springs are found along this river. One of the important springs is Terban spring that located at the north of Jetis Bridge, Terban sub-district, Yogyakarta City. This spring has an average annual discharge around 1 litre/second. It is still used by local residents for daily needs. However, on the top of the slope of this spring, an apartment will be built as shown in Figure 1. Therefore, people around Terban spring are worried that construction of the new apartment will cause the spring to die. Therefore, this study aims to examine how much the impact of apartment foundation towards the existing of Terban spring discharge. Groundwater modeling is used to predict the impact of apartment foundation that reaches below groundwater level. Groundwater modeling can be used as a tool to make future predictions on groundwater conditions...
due to the influence of human activities (Zhou and Li, 2011; Lachaal and Gana 2016). The groundwater flow model is also useful for managing groundwater in aquifers (Singh, 2013). This groundwater modeling application has also been widely used to predict the impact of groundwater abstraction at the airport area (Sheng and Devere, 2005; Druhan et al., 2008; Wilopo et al., 2018).

**Materials and Methods**

This research was conducted by using groundwater flow modeling through *Visual Modflow Ver. 3.1* software. Groundwater flow equation in three dimensions for water-saturated porous media is as follows:

\[
\frac{\partial}{\partial t} (K_x \frac{\partial h}{\partial x}) + \frac{\partial}{\partial y} (K_y \frac{\partial h}{\partial y}) + \frac{\partial}{\partial z} (K_z \frac{\partial h}{\partial z}) \pm Q = \frac{S_s}{t} \frac{\partial h}{\partial t} \tag{1}
\]

Where \( K_x \), \( K_y \), and \( K_z \) = hydraulic conductivity along the x, y, and z-axis (LT^{-1}); \( h \) = piezometric head (L); \( Q \) = volumetric flux per unit volume representing source/sink terms; \( S_s \) = specific storage coefficient defined as the volume of water released from storage per unit change in head per unit volume of porous material.

The groundwater balance approach can be used to evaluate changes in the amount of groundwater due to human activities. Groundwater balance study is a systematic activity that shows data about the recharge and groundwater use in the area within a certain period of time (Kumar and Seethapathi, 2002). Basic components of the groundwater balance are the input and output of the system that results in changes in groundwater storage over a period of time. Thus, groundwater balance equation can be formulated as follows (Rivera, 2000):
\[ \pm A\Delta\phi S = L_{\text{infl}} + R_{\text{va}} + R_{\text{vb}} - L_{\text{outfl}} - Q \]  

(2)

where: \( A\Delta\phi S \) = volumetric change in storage; \( A \) = area of balance (L\(^2\)); \( \Delta\phi \) = change in hydraulic head (L) and \( S \) = storativity (L\(^3\) x L\(^{-2}\) x L\(^{-1}\)), \( L_{\text{infl}} \) = Lateral groundwater inflow (L\(^3\)T); \( L_{\text{outfl}} \) = Lateral groundwater outflow (L\(^3\)T); \( R_{\text{va}} \) = Vertical water flow from above (L\(^3\)T); \( R_{\text{vb}} \) = Vertical groundwater flow from beneath (L\(^3\)T); \( Q \) = groundwater abstracted (L\(^3\)T).

Modeling of groundwater flow can be divided into two conditions, namely the steady-state model and the transient model. The steady-state model assumes that the magnitude and direction of groundwater flow are constant over time in all areas of the model. While the transient model assumes the magnitude and direction of groundwater flow change as a function of time (Anderson and Woessner, 1992). The accuracy of the groundwater flow model results is mainly decided by mean absolute error and normalized root mean square error (NRMS) of computed values for points on the graph (Anderson, 1992). Groundwater modeling can be accepted if the difference between calculation results and field measurements is less than 10% for the whole model area (Khadri and Pande, 2016; Du et al., 2018). In general, the calibration of groundwater flow models is done by modifying the values of several input parameters such as hydraulic conductivity, groundwater recharge, river stage and aquifer layer thickness in a limited range until the best results are obtained between model calculations and field measurements (Mayer et al., 2007).

To develop groundwater flow modeling in this paper, we used the data of sediment bedding and distribution along with hydraulic properties, groundwater recharge, model boundaries and apartment foundation design. Three points of drilling were carried out at the proposed locations to obtain sub-surface data. Measurements of river water levels at several points were also conducted to construct drain boundary condition. Sediment bedding data and aquifer characteristics were obtained from drilling log and pumping tests, as well as previous researchers. In addition, groundwater levels were measured at 19 dug wells around the construction site of the apartment with calibrating of the flow model, as shown in Table 1. The zone budget program was used for calculating the volume change of the groundwater flow discharge (Harbaugh, 1990) in the Visual Modflow program (Waterloo, 2001).

### Table 1. Groundwater level and river water level data.

| No | Well Code | Coordinate | Elevation (mSWL) | GWL Depth (m) |
|----|-----------|------------|----------------|--------------|
| 1  | SG1       | 430618     | 9140596        | 130          | 12.7       |
| 2  | SG2       | 430577     | 9140578        | 129          | 12.8       |
| 3  | SG3       | 430522     | 9140555        | 115          | 3.2        |
| 4  | SG4       | 430599     | 9140523        | 129          | 13.2       |
| 5  | SG5       | 430673     | 9140324        | 114          | 2.6        |
| 6  | SG6       | 430619     | 9140398        | 112          | 0          |
| 7  | SG7       | 430557     | 9140446        | 114          | 1.7        |
| 8  | SG8       | 430799     | 9140229        | 128          | 12.6       |
| 9  | SG9       | 430602     | 9140170        | 112          | 2.2        |
| 10 | SG10      | 430609     | 9140657        | 131          | 12.2       |
| 11 | SG11      | 430474     | 9140592        | 118          | 4.2        |
| 12 | SG12      | 430674     | 9140385        | 130          | 14.5       |
| 13 | SG13      | 430664     | 9140395        | 130          | 14.9       |
| 14 | SG14      | 430692     | 9140373        | 130          | 15.3       |
| 15 | SG15      | 430772     | 9140436        | 131          | 15.5       |
| 16 | SG16      | 430715     | 9140436        | 131          | 16.1       |
| 17 | SG17      | 430788     | 9140445        | 131          | 15.5       |
| 18 | SG18      | 430542     | 9140203        | 120          | 8.3        |
| 19 | SG19      | 430799     | 9140612        | 132          | 13         |
| 20 | RWL1      | 430622     | 9140176        | 107.7        |
| 21 | RWL2      | 430640     | 9140346        | 109.4        |
| 22 | RWL3      | 430537     | 9140427        | 110.1        |
| 23 | RWL4      | 430475     | 9140563        | 110.4        |

Note: SG = dug well; RWL = river water level.
Results and Discussion

Hydrology of the research area

Monthly rainfall data in the study area from 2007 to 2016 is shown in Figure 2. The highest rainfall occurred in December and January. According to annual rainfall data, the highest rainfall occurred in 2016 with an average rainfall of 3,056.9 mm/year, while the lowest rainfall occurred in 2009 with an average rainfall of 1,036 mm/year (BPS of Yogyakarta City, 2017). Overall, the average rainfall in the study area for 10 years is 2,170 mm/year, with an average temperature of 26.7 °C. Evaporation was calculated using the Singh (1992) equation, resulting in a value of 1,470 mm/year. With the research area of 0.27 km$^2$, surface runoff can be calculated, as 549 mm/year and groundwater recharge in the study area is 151 mm/year.

Hydrogeology of the research area

In order to understand the condition of sub-surface, there were three drilling points located inside the propose apartment area with the depth of each borehole reached 20 meters. The result from borehole data showed that the study area consists of coarse sand, fine-medium sand, sandy clay, clayey sand and clay as shown in Figure 3. All of them is still not consolidated. Based on stratigraphy information from drilling log, the hydro-stratigraphic model of the study area can be developed as shown in Figure 4. According to hydraulic permeability values of each type of sediment, it can be categorized into four types as shown in Table 2. Both fine-medium and coarse sand material are classified as an aquifer, and then sandy clay as an aquitard and clay layer is an aquiclude.

![Figure 2. Monthly rainfall and temperature during 10 years in the research area.](image)

Table 2. Permeability value of each material.

| No | Hydrogeology Unit | Material         | K (m/day) | Source                  |
|----|-------------------|------------------|-----------|-------------------------|
| 1  | Aquifer 1         | Coarse sand      | 90        | Field data              |
| 2  | Aquifer 2         | Medium-fine sand | 32        | Field data              |
| 3  | Aquitard          | Sandy clay       | 0.08      | Todd & Mays, 2005       |
| 4  | Aquiclude         | Clay             | 10$^{-8}$ | Todd & Mays, 2005       |
Figure 3. Cross-section of sub-surface condition based on borehole data.

Groundwater flow modeling

Groundwater flow modeling is carried out only in steady-state condition. The assumptions and boundary conditions used in this study area are as follows: 1) modeling only in the upper aquifer; 2) the aquifer system has boundary conditions in the form of specified head boundaries in the north, east, and west of model area, specified flow/drain boundaries in the south, and no-flow boundaries in the bottom part of the model; 3) aquifers are homogeneous and isotropic; 4) groundwater recharge value in the study area is considered to be the same in all research areas both before and after the apartment was built.

Figure 4. Conceptual of the geological condition in the research area.

Conceptual model

The conceptual model was created with the aim of being a simple description of the natural system conditions of the actual groundwater basin and consisting of the geological and hydrogeological conditions of the groundwater basin in the study area. The conceptual model was used as an understanding of the aquifer system of the research area, which was then mathematically modeled. The
conceptual model of the research area can be seen in Fig 5 and Fig 6. Hydro-stratigraphically, the study area can be divided into three layers of sediment based on the value of hydraulic conductivity, namely the coarse sand layer (K1) in the upper part, and then underneath the coarse-fine sand layer (K2) with lenses of sandy clay (K3) and the bottom part is clay layer. This clay is an impermeable layer, therefore is assumed no vertical groundwater flow from beneath.

**Model discretization**

The model area has a dimension of 510 m x 520 m. Discretion of the model area was carried out with the size per grid unit of 10 m x 10 m, while for the targeting area was 0.8 m x 0.8 m. A grid with an area of 100 m² was modeled area, while a grid with an area of 0.64 m² has targeted area, which is the location of the planned apartment (Figure 7).

**Groundwater flow model and model calibration**

Based on input data from the field and secondary data (initial model) and compared with groundwater level measurements (Table 1), the groundwater flow model was obtained with a SEE value of 0.364 meters, root mean squared (RMS) of 1.789 meters, the value of normalized RMS of 18.336%, and correlation coefficient of 0.812 as shown in Figure 8. RMS values that were still more than 10% indicating that the model is not good enough to be used. Therefore, it is necessary to calibrate the model by changing the values of the model input parameters. Calibration was carried out with trial and error by changing the parameters in the model to get the best value (Anderson and Woessner, 1992). In this model, calibration was conducted by changing groundwater recharge and hydraulic conductivity values into 12 scenarios, as shown in Table 3. Increasing of recharge value gave a better result in the model than lowering recharge value as shown in scenario 1 and 2. In addition, reducing hydraulic conductivity value from initial shown a better result. The best model can be achieved with a recharge parameter of 302 mm/year, hydraulic conductivity of coarse sand layer (K1) = 9 m/day, fine-medium sand layer (K2) 3.2 m/day, and sandy clay layer (K3) = 0.8 m/day as shown in Figure 9, with a SEE value of 0.237 meters, root mean squared (RMS) of 1.061 meters, the normalized RMS value is 9.39%, and the correlation coefficient is 0.924 as presented in Figure 9. The final groundwater modeling results are shown in Figure 10, which reveal that groundwater supplies the Code river. In general, shallow groundwater flow will follow the topography, while deep groundwater will be controlled by rock layers or geological structures (Brown et al., 2007).

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**Legend**

- **K1** = No flow boundary
- **K2** = Constant head boundary
- **K3** = River boundary

**Parameters**

- Precipitation = 2170 mm/year
- Evapotranspiration = 1470 mm/year
- Runoff = 549 mm/year
- Recharge = 151 mm/year

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**Figure 5. Hydrogeological conceptual model of the research area.**
Figure 6. Cross-section of the hydrogeological model.

Figure 7. Discretization of the groundwater model.
Figure 8. Graphic of calculated head versus measured head in the initial model.

Figure 9. Graphic of calculated head versus measured head in the calibrated model.
Tabel 3. Model calibration.

| Scenario   | Recharge mm/year | Hydraulic Conductivity K (m/day) | Normalized RMS (%) |
|------------|------------------|----------------------------------|--------------------|
| Initial Model | 151              | K1= 90; K2=32; K3=0.08          | 18.643             |
| Scenario 1  | 75.5             | K1= 90; K2=32; K3=0.08          | 18.143             |
| Scenario 2  | 302              | K1= 90; K2=32; K3=0.08          | 17.326             |
| Scenario 3  | 302              | K1= 45; K2=16; K3=0.04          | 16.554             |
| Scenario 4  | 302              | K1= 180; K2=64; K3=0.16         | 17.636             |
| Scenario 5  | 302              | K1= 54; K2=10; K3=8             | 14.124             |
| Scenario 8  | 302              | K1= 9; K2=5; K3=0.8             | 12.179             |
| Scenario 9  | 302              | K1= 12; K2=4; K3=0.8            | 11.331             |
| Scenario 10 | 302              | K1= 9; K2=3.2; K3=0.8           | 9.39               |
| Scenario 11 | 302              | K1= 6; K2=2; K3=0.8             | 10.452             |
| Scenario 12 | 302              | K1= 3; K2=1; K3=0.8             | 10.988             |

Figure 10. Comparison of the calculated and observed groundwater table.

**Impact prediction of Terban spring**

The planned apartment construction has 8 floors and two basement floors, therefore they use about 257 bore piles with a diameter of 80 cm and a depth of 12.5 m from the ground surface to support the building (Figure 11). While the depth of the groundwater level in the planned location of the apartment is around 8 meters. All bored piles will be inputted in a calibrated flow model as aquifuge (impermeable material). This bored pile has a zero value of permeability because it is made from concrete material. The area that influences groundwater flow into the spring is shown in Figure 12. This area is located between the planned location of the apartment and the spring, where all of the groundwater flow from this zone will exit through the spring. This zone boundary is determined from the groundwater flow nets. This area was used to calculate the amount of...
groundwater enters the spring based on the zone of budget. The results of calculations using the zone budget program in the **Visual Modflow** software show that before the foundation of the apartment was built, an inflow value appears 57.57827 m³/day and an outflow value reaches 57.58223 m³/day. While the calculation results after the foundation of the apartment was built obtained an inflow value of 55.20072 m³/day and an outflow value of 55.19808 m³/day as shown in Figure 12. The effect of apartment foundation on the changes in spring discharge will be examined by comparing groundwater inflow to the spring before and after the apartment is built. The difference in inflow before and after foundation construction is 2.377 m³/day or 0.027 liter/second. This value is around 4.12% from total previous inflow before construction of the foundation. Change of inflow was caused by the presence of apartment foundation that cut groundwater levels, thereby inhibiting groundwater flow rates.

![Figure 11 Position of bored pile in the model](image)

![Figure 12. Area of zone of budget with cover all of groundwater flow to the spring.](image)
Conclusion

The aquifer system in the study area is composed of two layers of aquifers. The first aquifer is composed of coarse sand deposits and the second aquifer is composed of fine-medium sand deposit with sandy clay lenses. While under the two layers, a clay layer is found. In general, groundwater flow in the study area leads to the Code River area, which Terban spring is located. Apartment construction in the top of the slope of Terban spring does not have a significant impact on the spring discharge, it can even be said no effect on the spring because the amount of decrease is only 0.027 litres/second or decrease 4% from the initial discharge before the apartment construction was built. This is because the foundation of the apartment is blocking the groundwater flow only in some parts of the aquifer. However, in order to maintain the Terban spring discharge to be stable or larger, the apartment is suggested to conserve groundwater by making recharge wells.

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