Aquifer Susceptibility to Groundwater Pumping in Kediri City, East Java Province, Indonesia

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Abstract. The development of Kediri City in various sectors, such as industry, agriculture, and population growth, also increases water. The utilization of groundwater is still a major mainstay in this area. The utilization of groundwater includes the construction of production wells for irrigation and raw water. The aquifer susceptibility should be considered during groundwater exploitation to minimize a negative impact on the environment. This research aims to analyze the susceptibility of the aquifer to pumping in Kediri City, which is helpful for planning and making decisions in the management of groundwater resources. The determination of aquifer susceptibility is based on aquifer response characteristics, aquifer storage characteristics, allowable subsidence of groundwater level, and depth to the groundwater table. Based on those parameters, it can be concluded that the aquifer susceptibility on groundwater utilization in Kediri City is at moderate and high levels. Areas with moderate aquifer susceptibility are located on the west side of Kediri City, and high aquifer susceptibility is in the middle to the eastern side of Kediri City.

1. Introduction
The development of Kediri City in various sectors, such as industry, agriculture, and population growth, will also be followed by increasing water. This city consist of 3 sub-districts is Mojoroto, Kota, and Pesantren. The groundwater is still a major source in this city due to the lack of surface water. The utilization of groundwater not only for daily purposes but also for irrigation by developing depth wells. The population growth of Kediri City from 2018 to 2019 was 0.74\% [1]. The production of drinking water by municipal waterworks (PDAM) of Kediri increased by 2.3 percent from 2018 to 2019 [1]. Excess use of groundwater can lead to a decrease in groundwater levels in wells, rivers, and lakes, causing a reduction in groundwater quality, land subsidence, causing higher costs for groundwater extraction and affecting the sustainability of groundwater resources [2-5]. Repairing aquifer damage due to over-pumping is very expensive [6]. Therefore, aquifer susceptibility should be considered during groundwater exploitation to minimize a negative impact on the environment.
Foster [7] and Adams & MacDonald [8] introduced the concept of aquifer susceptibility to the negative impacts of over-pumping groundwater. The negative of over-pumping can occur a decrease in groundwater level and the quantity of groundwater discharge [9]. Analysis parameters related to aquifer hydrogeological factors and groundwater recharge factors were carried out to identify aquifer susceptibility. Term susceptibility is used to avoid confusion with the term vulnerability, which is regularly related to aquifer vulnerability to pollution [8]. The potential impact of over-pumping can be identified before significant implications occur, and groundwater management measures can be taken to avoid or reduce unwanted effects [8]. The concept of susceptibility from the impact of exploitation is developed in the same way as vulnerability to pollution [10]. Aquifer susceptibility studies are among the essential strategies in groundwater management. It should be carried out in land use planning and groundwater resource development to help policymakers choose suitable sites for future reclamation [11], [12].

This research aims to analyze the susceptibility of the aquifer to pumping in Kediri City, which is helpful for planning and making decisions in the management of groundwater resources. The determination of aquifer susceptibility is based on aquifer characteristics, aquifer storage characteristics, allowable subsidence of groundwater level, and depth to groundwater level. An aquifer susceptibility map to groundwater pumping in Kediri City is obtained from those parameters analysis.

2. Methodology

This study uses parameters that must be considered in investigating aquifer susceptibility due to groundwater pumping include [7]:

1. Aquifer response characteristics are the result of dividing the transmissivity value by the storativity value. The well pumping test data obtained the value of transmissivity and storativity. The transmissivity of the aquifer is an important variable that affects the yield of pumped wells. The higher the transmissivity value, the greater the groundwater flowing in the aquifer and the lower the drawdown of the pump well [13].

2. Aquifer storage characteristics are the result of dividing the storativity value by the groundwater recharge value. The groundwater recharge value is calculated based on rainfall data in the study area.

3. Allowable subsidence of groundwater level/drawdown. It is calculated from the well-pumping test.

4. Depth to groundwater level is obtained by measuring the depth of the groundwater table in the resident's well.

Groundwater recharge value (R) can be calculated by the following formula [14]:

\[ R = P - Etr - RO \]  

where:

- \( P \) is the average rainfall in mm/year;
- \( Etr \) is evapotranspiration or loss of water to the atmosphere in mm/year;
- \( RO \) is surface water runoff in mm/year.

Scoring assessments are performed on each parameter. Each parameter has a score range from 1 to 4 according to their class, as shown in Table 1. The greater the score value, the greater the potential susceptibility of an aquifer to groundwater pumping. The sum of the scores for each parameter is used to determine the level of aquifer susceptibility to pumping. The sum of the scores with a total score of 13-16 is in the high susceptibility category. A total score of 9-12 includes the moderate susceptibility category. A total score of 4-8 consists of the low vulnerability category.

3. Result and Discussion

Based on the data from the pumping test on 33 wells, the transmissivity value of the aquifer in Kediri city is in the range of 0.84 to 683.39 m²/day. The storativity value of the aquifer in the Kediri City is in the range of 0.000045 to 0.000261. The aquifer response characteristics parameter in Kediri City is in the class >100,000 m²/day – 1,000 m²/day. According to Table 1, all areas of Kediri City have a score of 4 for the aquifer response characteristics parameter, as shown in Figure 1.
Based on equation (1), the groundwater recharge value in Kediri City ranges from 46.54 to 196.57 mm/year. The values of the aquifer storage characteristics parameter in Kediri City are in the class < 0.0001. All areas of Kediri City have a score of 1 for the aquifer storage characteristics parameter, as shown in Figure 2.

The drawdown value (allowable subsidence of groundwater level) in Kediri City ranges from 0.91 to 11.47 meters. The values of the drawdown (allowable subsidence of groundwater level) parameter in Kediri City are < 20 meters. All areas of Kediri City have a score of 4 for the drawdown parameter, as shown in Figure 3.

The depth to groundwater table in the Kediri City based on well measurements ranges 0.3 to 15 meters. Based on Figure 4, the western part of Kediri City has a groundwater table depth of 10 to 50 meters (score of 3), while the other area has a depth of fewer than 10 meters (score of 4).

**Table 1.** Scoring classification of susceptibility parameters [6].

| Parameter                          | Class                                      | Score |
|------------------------------------|--------------------------------------------|-------|
| Aquifer response characteristics    | >100,000 m²/day – 1,000 m²/day             | 4     |
|                                    | < 1000 m²/day – 100 m²/day                 | 3     |
|                                    | < 100 m²/day – 10 m²/day                   | 2     |
|                                    | < 10 m²/day                                | 1     |
| Aquifer storage characteristics     | > 0.1 - 0.01                               | 4     |
|                                    | < 0.01 - 0.001                             | 3     |
|                                    | < 0.001 - 0.0001                           | 2     |
|                                    | < 0.0001                                   | 1     |
| Allowable subsidence of groundwater level/drawdown | < 20 m                                    | 4     |
|                                    | > 20 m – 50 m                              | 3     |
|                                    | > 50 m – 100 m                             | 2     |
|                                    | > 100 m                                    | 1     |
| Depth to groundwater level         | < 10 m                                     | 4     |
|                                    | > 10 m – 50 m                              | 3     |
|                                    | > 50 m – 200 m                             | 2     |
|                                    | > 200 m                                    | 1     |

**Figure 1.** The Distribution Zone of Aquifer Response Characteristics Parameter Values in Kediri City
Figure 2. The Distribution Zone of Aquifer Storage Characteristics Parameter Values in Kediri City

Figure 3. The Distribution Zone of Drawdown Parameter Values in Kediri City

Figure 4. The Distribution Zone of the Depth to Groundwater Table in Kediri City
The result of overlying the four parameters shows that there are two zones of aquifer susceptibility to groundwater pumping in Kediri City: high susceptibility level (total score of 13 to 16) and moderate susceptibility level (total score of 9 – 12). Based on Figure 5, the western part of Kediri City has a high level of susceptibility, while the middle to the eastern part of Kediri has a moderate level of susceptibility.

![Figure 5. Map of Aquifer Susceptibility to Groundwater Pumping in Kediri City](image)

4. Conclusion
The aquifer susceptibility to groundwater pumping in Kediri City was developed based on the overlay of aquifer characteristics, aquifer storage characteristics, allowable subsidence of groundwater level, and depth to groundwater level parameters using GIS software. The aquifer susceptibility to groundwater pumping in Kediri City ranges from moderate (total score 9 to12) to high (13-16). Areas with high aquifer susceptibility are dominant in the Kediri City. Only a small part of the west has a low aquifer susceptibility. High aquifer susceptibility area to groundwater pumping due to shallower of groundwater table compare to other regions. This information can be used as basic information for groundwater quantity, especially in the high susceptibility area, and as a consideration for land use planning. In addition, it is necessary to regulate the construction of new groundwater wells and limit the pumping discharge in the high aquifer susceptibility area.

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