Estimation of Groundwater Recharge in Semarang City, Indonesia

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Abstract. In regional groundwater management, it is necessary to find out the water balance between the supply and demand of groundwater. One of the most important in analyzing the water balance of groundwater is groundwater recharge. Semarang city that has a groundwater management problem needs to know the groundwater recharge to analyze the groundwater balance. On the other hand, it is difficult to measure groundwater recharge accurately, consequently, the groundwater recharge should be estimated. There are several methods to estimate groundwater recharge. To verify the groundwater recharge estimation, more than one method of groundwater recharge estimation should be used. In this paper, the determination of groundwater recharge is using the Chaturvedi formula and Krishna Rao formula based on the amount of rainfall, and well level data method that based on the difference in water level. Based on the final results, the well level data method seems the best fit in estimating the groundwater recharge.

1. Introduction

Groundwater as part of the hydrological cycle is often overlooked because of its location, appearance, and invisible movement. However, groundwater is an important component in meeting raw water needs, especially in areas where surface water quality is poor.

As a renewable water source, knowing the amount of groundwater recharge is very important. But on the other hand, calculating groundwater recharge is not easy. For this reason, groundwater recharge analysis can be done by estimating and measuring using isotope, especially in carrying out groundwater management.

Groundwater recharge can be defined as water that is put into an aquifer when it rains, which occurs after the infiltration and percolation process, into the unsaturated zone [1]. Groundwater recharge depends on several factors, such as infiltration capacity, stochastic characteristics of rain, and climate factors [2]. There are several methods for estimating groundwater recharge, namely numerical approach, tracer method, hydrologic budget method, and multiple methods. Groundwater recharge can be estimated with several conventional methods, but unfortunately, these methods require a lot of analysis and hydrological data [3]. In the numerical approach method, the calibration process can be used to get the recharge flux needed to adjust the actual head [4]. In the tracer method, the most widespread use is in surface hydrology, where the water velocity is the greatest [5]. However, measurement using the tracer method can give results above or below estimation, because it does not
measure recharge directly [6]. Groundwater recharge estimation can also use the hydrologic budget method, which is recommended by the Groundwater Estimation Committee, India. However, the use of this method is limited to an area, where water table surveillance is carried out frequently [7].

Unfortunately, it is very difficult to judge the accuracy of each method of estimating groundwater recharge. For this reason, it is strongly recommended to estimate groundwater recharge using several methods by expecting consistency in the results, although consistency itself should not be taken as an indication of the accuracy of groundwater recharge estimates [8]. In this paper, the determination of groundwater recharge is using the Chaturvedi formula based on water level fluctuation methods and the amount of rainfall, and well level data methods that are based on the difference in water levels.

2. Study Area
Semarang City, the capital of Central Java, has an area of 373 km². The northern part of Semarang City is bordered by the Java Sea, the western side is bordered by Kendal Regency, the eastern side is bordered by Demak Regency, and the southern side is bordered by Semarang Regency, as shown in Fig. 1. The height of Semarang City is between 0.75 m to 348.00 m above the coastline.

3. Methodology
In Indonesia, rain is the most important component in recharging groundwater. In estimating groundwater recharge, it is easier to use empirical methods based on rain. This is because in Indonesia, rainfall data is easier to obtain when compared to other estimation methods. For this reason, in this paper, groundwater recharge estimation in Semarang City uses an empirical method based on the rain that occurred in Semarang City and its surroundings. However, to compare the empirical method with the actual conditions in the field, this paper also analyzes groundwater recharge estimation using the well level data method. However, to compare the empirical method with actual conditions in the field, this paper also analyzes groundwater recharge estimation using the well level data method.
Because of the limitations in estimating groundwater recharge, this study uses 3 empirical methods to estimate groundwater recharge. These methods are Chaturvedi formula, modified Chaturvedi formula, and well level data method.

3.1. Chaturvedi formula
In 1973, Chaturvedi derived the empirical relationship of recharge groundwater which is a function of annual precipitation based on the initial fluctuations in water and the amount of precipitation in Ganga-Yamuna as shown in [9]. The equation of the Chaturvedi Formula is shown in Eq. 1.

\[
R = 2.0(P - 15)^{0.4}
\]

where,
- \(R\) = recharge due to annual precipitation, inches
- \(P\) = annual precipitation, inches

Chaturvedi formula is ultimately used for preliminary estimations of groundwater recharge due to precipitation.

3.2. Krishna Rao
The Krishna Rao method (Eq. 2) provides groundwater recharge estimates in areas with limited and homogeneous climatology [9].

\[
R = K(P - X)
\]

Where:
- \(R\) = estimated recharge, inches.
- \(K\) = coefficient.
- \(P\) = annual precipitation, inches.
- \(X\) = mean annual precipitation.

The Krishna Rao method estimates a greater

\[
R = 0.20(P - 400) \quad \text{for areas with annual rainfall from 400 until 600 mm}
\]

\[
R = 0.25(P - 400) \quad \text{for areas with annual rainfall from 600 until 1000 mm}
\]

\[
R = 0.35(P - 600) \quad \text{for areas with annual rainfall above 2000 mm}
\]

3.3. Well level data method
Well level data method is a method of estimating groundwater recharge based on differences in water level in the observation wells at the beginning and end of the same water year by considering soil porosity [10]. The equation of the well level data method is shown in Eq. 3.

\[
R = (WL_2 - WL_1)p
\]

where:
- \(R\) = estimated recharge, inches.
- \(WL_2\) = water level at the beginning of the water year, inches.
- \(WL_1\) = water level at the end of the same water year, inches.
- \(p\) = adjusting for porosity 0.44 [11].

Well data method is considered more accurate because it estimates groundwater recharge based on measurements of water level in the observation well and considers the soil porosity.

4. Result and Discussion
Rainfall data used in the analysis of groundwater recharge estimation using the Chaturvedi formula and Krishna Rao in Semarang City is annual rainfall data from 1970 to 2016. While the water level data used for the well level data method is the water level data at the observation well. In groundwater analysis, the more points of observation wells are used, the results will be better and more in line with real conditions. However, due to the limited data length and the number of observation wells, this paper only uses two observation wells located in areas with high water fluctuation. at SMKN 10 from 1986 until 2010 and Wot Gandul, from 1977 until 2010. The location of the observation wells SMK 10 and Wot Gandul can be seen in Figure 2.

Based on the Chaturvedi and Krishna Rao methods, it appears that the estimated groundwater recharge has a very large range, ranging from 263.72 mm to 1106.21 mm. The results of the analysis of groundwater recharge estimates based on the Chaturvedi, Krishna Rao method, and the deviation from the mean precipitation is shown in Figure 3. The Krishna Rao method estimates a greater
groundwater recharge than the Chaturvedi method. The estimated amount of groundwater recharge decreases and increases according to the deviations from the average precipitation because in the Chaturvedi and Krishna Rao methods the estimation of groundwater recharge is only based on precipitation.

Based on the well level data method, the estimation of groundwater recharge in the observation well of SMKN 10 and Wot Gandul (Figure 4) does not show the same trend with the Chaturvedi and Krishna Rao methods, where groundwater recharge follows the deviation of average precipitation. This happens because the recorded data taken from the observation well is not only influenced by precipitation but is also affected by various things, including hydrogeological conditions and evaporation in the area.

Figure 2. Observation wells of Semarang City.
**Figure 3.** Groundwater recharge estimation based on Chaturvedi and Krishna Rao method, and deviations from the average of precipitation

Meanwhile, the relationship between groundwater recharge estimation and annual precipitation is shown in Figure 5. The relationship shows that the increase in precipitation affects the groundwater recharge increase by the equation $y = -0.0002x^2 + 0.2283x + 2780$.

**Figure 5.** Relationship of groundwater recharge estimation and annual precipitation

5. **Conclusions**
Based on the results and discussion, it shows that the Krishna Rao method gives the largest groundwater recharge estimate when compared to the other two methods. The Chaturvedi method is a
groundwater recharge estimation method that is quite easy to use but is more suitable for areas that have small evaporation, or the evaporation value can be ignored.

For areas that have high evaporation values such as Semarang City, the most appropriate method for estimating groundwater recharge is the well level data method. The well level data method can also be used in other areas. After all, it is considered more by local conditions, because it is based on groundwater level measurements in the observation well.

6. References

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