Groundwater Resources Estimation in the Middle of Randublatung Groundwater Basin Based on Geoelectrical Investigation

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Abstract. The high groundwater use in the Randublatung Groundwater Basin area relates to groundwater abstraction for agriculture. Therefore, a question arises on how much groundwater resources in this area may support agricultural groundwater usage. This research has the objective to quantify the groundwater resources in this area. This research conducts a geoelectrical investigation to identify the aquifer's lithology and observe the groundwater level. The research reveals that resistivity values of subsurface rock layers in the research area range from 0.13 to 124.86 Ωm. The aquifer layer consisted of two aquifer systems, with the hydraulic conductivity varies of the aquifer layer is 0.0001 cm/s until 0.01 cm/s. The aquifer layers estimated to be found at depths vary 5 – 90 m from the ground with thickness range from 10 to 70 m. Meanwhile, the aquiclude layers consisted of clay, silty clay, and sandy clay was estimated to be found at depths varies 0 – 50 m from the ground with thickness varies from 5 to 65 m. by combining those data with a hydraulic gradient of groundwater flow, the dynamic groundwater resources in the research area is estimated between 50 m³/day and 4,691 m³/day.

key words: geoelectrical method, groundwater resources, hydrostratigraphy, Randublatung groundwater basin

1. Introduction

Groundwater resource has strategic value considering its extensive use for household, industrial, irrigation, and other needs. In addition, groundwater management is necessary to avoid groundwater degradation, both in quantity and quality [1].

Groundwater use in the Randublatung groundwater basin area increases rapidly, especially in the Randublatung, Kedungtuban, and Kradenan District, Blora Regency. Many deep wells are made to abstract groundwater for supplying irrigation water (Figure 1) [2,3]. The over-pumping activities on groundwater resources may cause several negative impacts on the environment, such as declining groundwater levels and land subsidence. Therefore understanding the groundwater resources available in this region is vital as basic information for the management of the well to ensure sustainable use of groundwater and become the objective of this research.
It is well known that the more significant groundwater resources, the higher capacity of the aquifer [4,5]. A well-known method to estimate the groundwater resources and aquifer capacity is by conducting geoelectrical and hydrogeological field observation. Geoelectrical investigation result is resistivity data. The characteristics of the aquifer can be seen from the interpretation result of the VES geoelectrical investigation. After the aquifer layers are known, data on the depth of the aquifer and the thickness of the aquifer at the research area can be determined to calculate Darcy’s Formula to see the groundwater resources estimation.

Figure 1. Research Area: Kedungtuban, Randublatung, and Kradenan District, Blora Regency, Central Java, in the middle Randublatung Groundwater Basin [6].

2. Material and methods

2.1. Geological and Hydrogeology Analysing
As shown in Figure 1, the location of the Randublatung groundwater basin is in the Blora Regency of Central Java. Based on Geological Map, Randublatung groundwater basin in between Rembang Hill and Kendeng Hill [7,8]. The research area comprises alluvial deposits consisting of sand, gravel, clay, silt, claystone, limestone, marl, sandstone, and sandy clay. It is deposited along the Lusi River, Madiun River, Wulung River, and Bengawan Solo River [7–9]. The formation of rock from older are : Kerek (Tmk), Wonocolo (Tmw), Ledok (Tmpl), Kalibeng (Tpk), Klitik (Tpkk), Sonde (Tpso), Mundu (Tpm), Selorejo (Tps), Lidah (QTI), Tambakromo (QTpt) and Alluvium Deposits (Qa) [7,8,10].

Based on the hydrogeological map in Figure 2, Randublatung Groundwater Basin had three aquifer systems: extensive productive aquifers, moderately productive aquifers, and locally productive aquifers. The aquifer layer consisted of silty sand, fine sand, and coarse sand. Based on Table 1 the conductivity varies of the aquifer layer is 0.0001 cm/s until 0.01 cm/s.

| Material                                | Hydraulic Conductivity (cm/s) |
|-----------------------------------------|------------------------------|
| Clay                                    | $10^{-9}$ – $10^{-6}$        |
| Silt, sandy silts, clayed sands, till   | $10^{-6}$ – $10^{-4}$        |
| Silty sands, fine sands                 | $10^{-5}$ – $10^{-3}$        |
| Well-sorted sands, glacial outwash      | $10^{-3}$ – $10^{-1}$        |
| Well-sorted gravel                      | $10^{-2}$ – 1                |
2.2. Geoelectrical Investigation

The purpose of geoelectrical investigation in groundwater prospecting is actually to identify aquifer occurrence. Vertical Electric Sounding (VES) is a geoelectrical measurement method that is commonly used due to its cost-effectiveness. However, it reveals good subsurface characterization for groundwater resource estimation [13–15]. In the VES method, four electrodes are grounded where two electrodes are current electrodes, and the other two are potential electrodes [13,15].

There are several known configurations of measurement; one of them is the Schlumberger configuration. This configuration is most often used to find groundwater resources. Ideally, the MN (potential) distance is made as small as possible so that the theoretical MN distance does not change due to the limited sensitivity of the measuring instrument. Then when the AB (current) distance is relatively large, the MN distance should be changed. However, the change in MN distance should not be more significant than one-fifth of the AB (current) distance (Figure 3) [16,17]. The Schlumberger configuration (Figure 3) was chosen because it can detect the non-homogeneous rock layers on the surface and is easy to use [16,18].

The results of the geoelectrical measurement data are resistivity. Different values of resistivity will be measured on the different types of soils/rocks [19]. Resistivities of rock formations vary over a wide range, depending on the material, density, porosity, pore size and shape, water content and quality, and temperature (Figure 3) [20]. Actual resistivities are determined from apparent resistivity, computed from measurements of current and potential differences between pairs of electrodes placed in the ground surface [20]. The expression for the apparent resistivity is given by Equation (1) [21]. The apparent resistivity was plotted against half current electrode spacing on a double logarithmic paper.

\[
\rho_a = \pi \left[ \frac{AB}{2} \right]^2 \frac{\Delta V}{I} \frac{(MN/2)^2}{MN} \Delta V
\]

(1)

Where: \( \pi \) is coefficient \( \frac{22}{7} \), AB is current electrode spacing in meter, \( \Delta V \) is potential differences in volts, MN is potential electrodes spacing in meter, I is electric current in Amperes.
2.3. Groundwater Resources Estimation

The groundwater resource in an aquifer comes from rainfall that experiences infiltration and then becomes groundwater flow from upstream to downstream. In calculating the potential for groundwater resources, to find groundwater flow discharge from the aquifer ($Q$) needed several data areas the primary inputs: the conductivity of the rock ($K$) (Table 1), the area of the aquifer layer ($A$), water table fluctuation ($\partial h$), aquifer length ($L$), aquifer thickness ($b$) and aquifer width ($W$). The initial calculation calculates the subsurface flow discharge, calculated by Darcy's Formula (Equation (2)) below [11].

$$Q = K \times W \times b \times \frac{\partial h}{\partial L}$$ (2)

2.4. Methodology

To achieve the defined objective, this research methodology is differentiated into four steps: literature study, collecting data, analyzing data, and conclusion. The primary data from this research are observations about the groundwater level from wells and geoelectrical investigation. Secondary data are administration map, topography, hydrology, geological and hydrogeological of Randublatung groundwater basin. Seventy-fourth of wells and 20 geoelectrical investigation points are collected for primary data, as shown in Figure 5 below.
Figure 5. Distribution of observation location in the research area

Geoelectrical investigation data from measurement is the apparent resistivity. The apparent resistivity formula is given by Equation (1). Appropriate resistivity data is obtained and then processed, which consists of four stages: data input, model estimation parameters (matching curve), model iteration parameters (inverse modeling), and interpretation iterated data (interpreting data). Data processing with the program will produce a vertical cross-section of the layered soil, often called borehole logging, which describes each layer's resistivity value (true resistivity).

Aquifers are usually found in sandy or porous layers. The characteristics of the aquifer can be seen from the interpretation result of the VES geoelectrical investigation. After the aquifer layers are known, data on the depth of the aquifer and the thickness of the aquifer at the research area can be determined to calculate Darcy's Formula from Equation (2). Based on Figure 6, it can be seen that if the groundwater flows to the East, then the length of the aquifer is the average length of cross-sections A and B. Meanwhile, the aquifer width is the length of cross-sections 1.

The pattern of groundwater distribution was analyzed using Surfer software so that the contours of the soil and the flownet were obtained. Groundwater flow serves to indicate the direction of water flowing.

3. Result and discussion

3.1. Observation Wells and Flownet
A total of 74 points were collected from observation wells. Based on groundwater level data from 74 wells, a recent groundwater elevation contour map is developed. The water table varies between 21 masl to 123.6 masl. The groundwater flow from the hills to the Bengawan Solo River and the north as the river’s flow, shown in Figure 6. Based on this groundwater contour, the hydraulic gradient can be determined and is about 0.0025 and 0.0027.

3.2. Aquifer Characteristics
The results of geoelectrical data processing obtained the value of rock type resistivity in the research area varies 0.13 – 124.86 Ωm. In this range, the resistivity value intervals can be grouped based on the different resistivity and electrical conductivity of rocks presented in Table 2. The results of the geoelectrical analysis illustrate that, in general, the research area is composed of clay, silty clay, sandy clay, silty sand, fine sand, and coarse sand. The aquifer is composed of silty sand, fine sand, and coarse sand. The rock layers that make up the aquifer are obtained from the lithology estimation of the resistivity data on the borehole logging (Figure 6). From Figure 6, it can be concluded that the aquifer
system in the research area consists of two layers of aquifers. Based on Figure 6 also, the aquifer estimated to be found at depths varies 5 – 90 m from the ground. Therefore, the thickness of the aquifer range from 10 to 70 m.

Meanwhile, the aquiclude is composed of clay, silty clay, and sandy clay. The layer estimated to be found at depths varies 0 – 50 m from the ground. The thickness of the aquiclude varies from 5 to 65 m (Figure 6).
Table 2. Lithology estimation of the resistivity data

| Resistivity (Ωm) | Lithology Estimation |
|------------------|----------------------|
| 0 – 5            | Clay                 |
| 5.1 – 9.99       | Silty Clay           |
| 7 – 15           | Sandy Clay           |
| 15.1 – 50        | Silty Sand           |
| 50.1 – 100       | Fine Sand            |
| > 100            | Coarse Sands         |

3.3. Groundwater Resources Estimation

Darcy’s formula is used to calculate groundwater resources estimation in the aquifers. The parameter value in Darcy’s Formula was obtained from the analysis of the aquifer characteristics in the research area. Based on the cross-section in Figure 6 and Equation (2), the generated value of groundwater resources is estimated below in Table 3.

Table 3. The Result of the groundwater resources estimation

| Parameters                              | Worst Scenario | Optimum Scenario | Unit       |
|-----------------------------------------|----------------|------------------|------------|
| The conductivity of the rock (K)        | 0.0864         | 8.64             | m/day      |
| Average aquifer thickness (b)           | 35             | 30.67            | m          |
| Average aquifer width (W)               | 6555           | 6556             | m          |
| The area of the aquifer layer (A)       | 229425         | 201050.67        | m²         |
| Aquifer length (l)                      | 5850.3         | 5850.8           | m          |
| Hydraulic gradient (i)                  | 0.00255        | 0.00270          | m³/day     |
| Groundwater resources (Q)               | 50.5           | 4691             | m³/day     |

Table 3 shows the parameter values of Darcy’s formula and the potential value of groundwater resources in the aquifer. On this table, there are two scenarios: worst and optimum, depending on the value of hydraulic conductivity. Based on calculations, the potential value of groundwater resources in the middle of the Randublatung groundwater basin is between 50.5 m³/day to 4,691 m³/day. The real groundwater resources value may be in the average of this calculation. Still, it must be proven scientifically based on the real hydraulic conductivity value, existing borehole logging, and pumping test result, which will continue this research.

4. Conclusion

According to the result of this research, based on the geoelectrical survey and interpretation, there are two layers of aquifer existing in the research area. The aquifer layer consisted of silty sand, fine sand, and coarse sand, with the conductivity may vary from 0.0001 cm/s to 0.01 cm/s. The aquifer layer estimated to be found at depths varies 5 – 90 m from the ground with thickness range from 10 to 70 m. Meanwhile, groundwater level measurement shows that the regional groundwater flows from higher areas to Bengawan Solo River with a hydraulic gradient between 0.0025 and 0.0027. Based on the estimation by using Darcy Formula, the groundwater resources estimation in the research area may be between 50.5 m³/day to 4,691 m³/day. The actual aquifer layer and aquifer capacity still must be proven by comparing the result of the geoelectrical survey with data of existing log bore and pumping test.

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