Comparative study of geohydraulic estimation: a case study of Kertajati, Majalengka, Indonesia

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Abstract. The declining quality of surface water resources leads to groundwater exploitation as a source of fresh water. The developing urban environment also increases the need for groundwater resources as freshwater. Each rock in a geology formation has a different ability to transmit groundwater. There are various ways to obtain parameters of hydraulic conductivity and groundwater transmissivity. The common method were time and cost consuming. The new method for estimation of geohydraulic parameter were needed. This paper aims to estimate geohydraulic parameter using different techniques and approaches and compares them. Geohydraulic parameter based on Heigold approach show the value of transmissivity at the study area in the range of 22.8 - 1307 m²/day. Geohydraulic parameter based on Niwas and Singhal approach indicate the value of transmissivity at the study area in the range of 32.55 - 30245 m²/day. The highest hydraulic conductivity and transmissivity values were in the southern and northern parts of the study area. In general, the estimation approach was able to estimate the geohydraulic value at the study area.

1. Introduction

Water is a basic human need [1], [2]. The declining quality of surface water resources leads to groundwater exploitation as a source of fresh water [3], [4]. The developing urban environment also increases the need for groundwater resources as freshwater [5]. Groundwater flows through the grains, fractures, and fissures of rock formation [4]. Groundwater flows below the surface at different flow rates depending on the geological conditions [6]. Each rock in a geological formation has a different ability to transmit groundwater [7]. Parameters or measurements that can describe the ability of the geological formation to transmit water are called hydraulic conductivity [8].

There are various ways to obtain parameters of hydraulic conductivity and groundwater transmissivity [7], [9]–[11]. Hydraulic conductivity and groundwater transmissivity can be obtained in both the field and laboratory. One method commonly used to determine hydraulic conductivity and transmissivity in the field is the pumping test method [12]–[16]. However, this method is very time consuming and requires a very high cost. Some researchers try to overcome this difficulty by using the Geohydraulic parameter approach [17]. Geohydraulic parameters are the parameters of rock hydraulics (hydraulic conductivity, transmissivity & storativity), which are derived through the geoelectric approach [18], [19].

Geoelectric methods for groundwater studies have been carried out by researchers [14], [20], [21]. This method utilizes resistivity parameters to determine subsurface conditions [22] where rocks that are saturated with groundwater will have a lower resistivity value than the same rocks that are not saturated with groundwater [23].
Many researchers have utilized the resistivity value to obtain hydraulic conductivity and transmissivity [14], [24], [25]. However, determining the geohydraulic parameters using a conventional field study time consuming and waste a lot of cost. Therefore, an approach is needed that can estimate the geohydraulic value that is close to the conventional geohydraulic value. This paper presents the results of geoelectric method to estimate the hydraulic conductivity and transmissivity in the Kertajati Aerocity construction site and to compare the results with pumping test data [26].

Kertajati area is projected to become a new economic and business center by the West Java Provincial Government. This region will develop into Kertajati Aerocity, where the Kertajati International Airport is an important part of the project. Geologically, the Kertajati area has a unique formation composed of volcanic rocks (Qos) and alluvium (Qa). These two formations have different groundwater characteristics. According to [35], the research area can be classified as an area with medium aquifer productivity.

2. Material and Methods

Table 1. Vertical Electrical Sounding (VES) Point

| VES Points | Lon   | Lat   | Easting | Northing | Z (m) |
|------------|-------|-------|---------|----------|-------|
| MJL1       | 108.1786 | -6.62436 | 188005 | 9266890 | 69    |
| MJL2       | 108.1297 | -6.6795  | 182632 | 9260756 | 66    |
| MJL3       | 108.1781 | -6.5405  | 187904 | 9276171 | 40    |
| MJL4       | 108.1586 | -6.62777 | 185793 | 9266500 | 69    |
| MJL5       | 108.1817 | -6.64369 | 188368 | 9264752 | 66    |
| MJL6       | 108.1987 | -6.65247 | 190249 | 9263791 | 68    |
| MJL7       | 108.1067 | -6.64422 | 180059 | 9264646 | 74    |
| MJL8       | 108.1259 | -6.6592  | 182193 | 9263000 | 66    |
| MJL9       | 108.1483 | -6.66887 | 184677 | 9261944 | 66    |
| MJL10      | 108.1677 | -6.68682 | 186837 | 9259970 | 66    |
| MJL11      | 108.0999 | -6.59537 | 179275 | 9270048 | 40    |
| MJL12      | 108.169  | -6.73927 | 187017 | 9254166 | 65    |

There are twelve VES measurement points as presented in Table 1. VES measurement points are located around the Kertajati aerocity area. Geoelectric measurements were made on Tuffaceous sandstone and alluvium rock formations. Measurements were made using the GL-4200 Earth Resistivity meter geoelectric device. Schlumberger array configuration was used to obtain resistivity with a spacing electrode from 1.5 meters to 150 meters [20], [27], [28]. Field measurement data in the form of potential difference (V) and current (I) were then recorded on the measurement datasheet. The coordinates of the measurement points were recorded using the Garmin 64s GPS. The apparent resistivity value was calculated using the following equation (1) [21]:

\[ \rho_a = K \frac{\Delta V}{I} \]

, where \( \rho_a \) is the apparent resistivity, \( K \) is the configuration factor, \( \Delta V \) is the potential and \( I \) is the current.

Because the apparent resistivity value is still dependent on the value of the resistivity layer above it, it is necessary to use inversion techniques to obtain the value of true resistivity. In this study, IPI2Win developed by Moscow University [20], [29], was used to get the value of true resistivity of each layer. Lithology interpretation is done by using literature study in previous research. The resume of inversion and interpretation results are presented in Table 3.
2.1. Estimation of hydraulic conductivity

[32] obtained hydraulic parameters using the Dar Zarrouk approach. The results of that approach produce transmissivity values of:

\[ 1.55 \times R \]  \hspace{1cm} (2)

where \( R \) is the value of the transverse resistance that can be obtained through the following equation:

\[ R = h \rho \]  \hspace{1cm} (3)

where \( h \) is the aquifer thickness, and \( \rho \) is the aquifer resistivity. The hydraulic conductivity of aquifer \( (K) \) obtained with:

\[ K = \frac{T}{h} \]  \hspace{1cm} (4)

where \( K \) is the hydraulic conductivity, \( T \) is the transmissivity of the aquifer, and \( h \) is the thickness of the aquifer.

According to [31], the hydraulic conductivity value can be obtained using equation (5):

\[ K = 386.40 R_{rw}^{-0.93283} \]  \hspace{1cm} (5)

where \( K \) is the hydraulic conductivity and \( R_{rw} \) is the resistivity of the water-saturated aquifer.

2.2. Hydraulic conductivity maps

To visualize the hydraulic conductivity of the calculation results, Arcgis Pro 2.6 was used with the Inverse Distance Weighted (IDW) gridding technique [30], [31]. The IDW method has been widely used by researchers because of its reliability in interpolating a calculation result. Comparison is done qualitatively. There is a value of transmissivity in the study area in previous studies (Table 2).

Table 2. Transmissivity values from the previous studies

| Well ID | Longitude | Latitude | Transmissivity (m²/day) |
|---------|-----------|----------|-------------------------|
|         |           |          | Waspodo (2002) [34]     |
| TW-01   | 108.1386  | -6.67356 | 99                      |
| TW-88   | 108.1797  | -6.61515 | 26.4                    |
| TW-107  | 108.1044  | -6.65392 | 613                     |
| TW-108  | 108.1722  | -6.6841  | 141.9                   |
| TW-116  | 108.1303  | -6.68755 | 99                      |
| TW-132  | 108.131   | -6.63342 | 1320                    |
| TW-133  | 108.165   | -6.62466 | 25.4                    |
| TW-135  | 108.1394  | -6.66103 | 689.7                   |
| TW-136  | 108.1065  | -6.65949 | 135                     |
| TW-137  | 108.109   | -6.68791 | 224.4                   |
|         |           |          | Gemulus (2016) [33]     |
|         |           |          | 1346.4                  |

3. Results and Discussions

Table 3 shows the results of geoelectric inversion modeling. The resistivity layer model varies from four to seven resistivity layers consisting of topsoil, sand, and clay with various resistivity values.

In general, resistivity values in the study area can be divided into five resistivity zones: very low resistivity zone, low resistivity zone, medium resistivity zone, high resistivity zone, and very high resistivity zone. Very low resistivity zones have a range of resistivity values from 1 Ωm to 10 Ωm, for low resistivity zones it has a range of resistivity values from 10 Ωm to 50 Ωm, for medium resistivity zones has a range of resistivity values from 50 Ωm to 100 Ωm, for high resistivity zones, has a range of resistivity values from 100 Ωm to 200 Ωm, for very high resistivity zones having resistivity values > 200 Ωm [32]. The study area is dominated by a low resistivity zone associated with clay layers.
### Table 3. Vertical Electrical Sounding interpretation

| VES No. | No of Layers | Resistivity (Ohm-m) | Thickness (m) | Depth (m) | Inferred Lithology |
|---------|--------------|---------------------|---------------|-----------|--------------------|
| MJL1    | Layer 1      | 141                 | 1             | 1         | Top Soil           |
|         | Layer 2      | 14                  | 1             | 2         | Top Soil           |
|         | Layer 3      | 31                  | 3             | 5         | Sand               |
|         | Layer 4      | 14                  | 9             | 14        | Clay               |
|         | Layer 5      | 34                  | 24            | 38        | Sand               |
|         | Layer 6      | 5                   | 64            | 102       | Clay               |
|         | Layer 7      | 233                 | 48            | 150       | Sand               |
| MJL2    | Layer 1      | 1                   | 3             | 3         | Top Soil           |
|         | Layer 2      | 5                   | 3             | 6         | Clay               |
|         | Layer 3      | 1                   | 7             | 13        | Clay               |
|         | Layer 4      | 133                 | 27            | 40        | Sand               |
| MJL3    | Layer 1      | 45                  | 1             | 1         | Top Soil           |
|         | Layer 2      | 8                   | 2             | 2         | Top Soil           |
|         | Layer 3      | 13                  | 69            | 71        | Clay               |
|         | Layer 4      | 2474                | 79            | 150       | Sand               |
| MJL4    | Layer 1      | 22                  | 3             | 3         | Top Soil           |
|         | Layer 2      | 82                  | 2             | 5         | Clay               |
|         | Layer 3      | 8                   | 5             | 9         | Clay               |
|         | Layer 4      | 298                 | 12            | 22        | Sand               |
|         | Layer 5      | 1                   | 98            | 120       | Clay               |
| MJL5    | Layer 1      | 54                  | 1             | 1         | Top Soil           |
|         | Layer 2      | 1                   | 1             | 2         | Sand               |
|         | Layer 3      | 15                  | 3             | 4         | Clay               |
|         | Layer 4      | 1                   | 9             | 13        | Clay               |
|         | Layer 5      | 7                   | 137           | 150       | Sand               |
| MJL6    | Layer 1      | 1                   | 1             | 0.75      | Top Soil           |
|         | Layer 2      | 13                  | 1             | 1.95      | Top Soil           |
|         | Layer 3      | 1                   | 18            | 19.9      | Clay               |
|         | Layer 4      | 6                   | 130           | 150       | Sand               |
| MJL7    | Layer 1      | 1                   | 0.75          | 0.75      | Top Soil           |
|         | Layer 2      | 4                   | 4.24          | 4.99      | Clay               |
|         | Layer 3      | 2                   | 18.1          | 23.1      | Clay               |
|         | Layer 4      | 7                   | 126.9         | 150       | Sand               |
| MJL8    | Layer 1      | 42                  | 1             | 1         | Top Soil           |
|         | Layer 2      | 9                   | 8             | 9         | Clay               |
|         | Layer 3      | 41                  | 91            | 100       | Sand               |
| MJL9    | Layer 1      | 3                   | 1             | 1         | Top Soil           |
|         | Layer 2      | 19                  | 1             | 2         | Top Soil           |
|         | Layer 3      | 1                   | 3             | 5         | Clay               |
|         | Layer 4      | 27                  | 12            | 17        | Clay               |
|         | Layer 5      | 1                   | 83            | 100       | Sand               |
The calculated geohydraulic parameters show varying values (Table 4). The detail about the interpretation in the study area can be found in [32]. The geohydraulic value estimation using the Heigold’s approach [33] shows quite different values when compared to the estimated using the Niwas and Singhal approach [34] (Figure 1 and 2). According to [26], the transmissivity value in the study area is in the range of 80.2 - 1346 $m^2/day$, while according to [35], the transmissivity value in the study area is in the range of 26.4 - 1320 $m^2/day$. The results of calculations using the Heigold approach [31] show the value of transmissivity at the study area is in the range of values 22.8 - 1307 $m^2/day$. The results of calculations using the Niwas and Singhal approach [32] indicate the value of transmittance at the study area is in the range of values 32.55 - 30245 $m^2/day$. Thus, the Niwas and Singhal approaches [32] produced over-estimated values compared to the field measurement values [33, 34].

Table 4. Geohydraulic estimation

| ID     | Longitude  | Latitude  | $h$ (ohm.m) | $\rho$ | Heigold [31] $K$ = $386.40R_{tr}^{0.93283}$ | Heigold [31] $T$ = $K \cdot h$ | Transverse Resistance (TR) | Niwas and Singhal [32] $K$ = $1.55 \cdot T$ | Niwas and Singhal [32] $T$ = $T/h$ |
|--------|------------|-----------|-------------|--------|---------------------------------|-----------------|-----------------------------|-------------------------------|-----------------------------|
| MJL 1  | 108.17     | -6.62     | 3           | 31     | 15.69 47.09 93.00 144.15 48.05 |                  |                             |                               |                             |
| MJL 2  | 108.12     | -6.67     | 27          | 133    | 4.03   108.94 3591.00 5566.05 206.15 |                  |                             |                               |                             |
| MJL 3  | 108.17     | -6.54     | 79          | 247    | 2.26   178.93 19513.00 30245.15 382.85 |                  |                             |                               |                             |
| MJL 4  | 108.15     | -6.62     | 12          | 298    | 1.90   22.81367 3576.00 5542.80 461.9 |                  |                             |                               |                             |
| MJL 5  | 108.18     | -6.64     | 9           | 7      | 62.91 566.17 63.00 97.65 10.85 |                  |                             |                               |                             |
| MJL 6  | 108.19     | -6.65     | 18          | 6      | 72.63 1307.45 108.00 167.40 9.30 |                  |                             |                               |                             |
| MJL 7  | 108.10     | -6.64     | 18          | 7      | 62.90 1132.34 126.00 195.30 10.85 |                  |                             |                               |                             |
| MJL 8  | 108.12     | -6.65     | 8           | 41     | 12.09 96.75 328.00 508.40 63.55 |                  |                             |                               |                             |
| MJL 9  | 108.14     | -6.66     | 21          | 1      | 386.40 8114.40 21.00 32.55 1.55 |                  |                             |                               |                             |
| MJL 10 | 108.1677   | -6.68682  | 21          | 258    | 2.174733 45.66939 5418 8397.9 399.9 |                  |                             |                               |                             |
| MJL 11 | 108.0999   | -6.59537  | 15          | 33     | 14.80886 222.133 495 767.25 51.15 |                  |                             |                               |                             |
| MJL 12 | 108.169    | -6.73927  | 10          | 33     | 14.80886 148.0886 330 511.5 51.15 |                  |                             |                               |                             |
The value of hydraulic conductivity and transmissivity shows the difference between estimates using the Heigold and Niwas and Singhal approaches [31, 32]. Based on the calculation using the approach[31], the hydraulic conductivity values at the study area are in the range of 1.9 - 72.6 m/day. The largest hydraulic conductivity and transmissivity value is in the middle of the study area. Based on the Niwas and Singhal approach [32], the highest hydraulic conductivity and transmissivity values were in the southern and northern parts of the study area (Figure 1).

Figure 1. Hydraulic Conductivity value using (a) Heigold et al.(1979) and (b) Niwas and Singhal (1980) approach
The difference in geohydraulic parameter values is due to the simplification of estimations in the Heigold and Niwas and Singhal approaches [31, 32]. The field hydraulic conductivity and transmissivity are strongly influenced by porosity, permeability, and rock age. Because both approaches are simplifications, the difference in values is common. In general, both approaches were able to estimate the geohydraulic value in the study area. There are many things that cause the high value of the estimation using the two methods, but the most dominant is the geological conditions at the study area.

![Figure 2. Transmissivity value (a) using [34] approach (b) [33] approach (c) using [31] approach (d) using [32] approach](image)

4. Conclusions
The geoelectric results show that the study area is dominated by a low resistivity zone associated with the presence of a clay layer. Although the estimated values tend to be overestimated, these methods can be used to estimate hydraulic parameters regionally. Both methods can estimate geohydraulic values of well. However, overestimated the Niwas and Singhal method [32]. Generally, the highest hydraulic conductivity and transmissivity values are in the middle of the study area. Because both methods are simplified, overestimation is possible.

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