A Geoelectric Approach for Karst Groundwater Analysis

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Abstract. Artesian well is one of the major efforts to obtain water source for fulfilling water demands in Eroniti Conservation park, Ponjong, Yogyakarta by drilling deep into several soil layers. Vertical Electrical Sounding (VES) method is the most common approach to determine the existence of groundwater. The method probes layers of rock below the ground surface based on their electrical properties, since the electrical resistivity of each layer is theoretically different. This study aims to utilize the VES approach for investigating the properties of the rock layers in the area to explore groundwater sources. We install six different VES points in the observation area using Schlumberger electrode configuration. The methodology of the work consists of three steps: the planning of the placement of the sounding points, the measurement step performed by a unit of IRIS SYSCAL Resistivity meter, and the data analysis and interpretation. Employing the resistivity analysis, we conclude that the observed region consists of Mediterranean soil as a result of weathering of limestone as well as lithology of the limestone. Furthermore, there are two types of aquifer found in the area: a perched aquifer found 27 meters below the ground surface of VES point 1 and a confined aquifer 166 meters below the ground surface of VES point 2 and 6.

Keywords: aquifer, geoelectric method, geophysics, groundwater, resistivity

1. Introduction
Artesian wells are considered to have major importance for obtaining groundwater sources in some areas by drilling into the ground through several layers of soil/rock. The area may be greatly benefitted from the groundwater sources and knowledge and prediction of climate conditions which is required to estimate adequate water availability, especially for various agricultural activities in the region [1–5]. To obtain groundwater sources, one method that is often used to explore the condition of groundwater
flow is the geoelectric sounding method. The method is the most commonly used approach for subsurface rock investigation that aims to provide information about the rock layers below the ground surface. Vertical Electric Sounding (VES) is a geoelectric survey technique intended to determine the rock layers from their electrical properties where each type of soil/rock has a different electrical conductivity [6]. Likewise, the water saturation also greatly affects the electrical properties of the rock. This geophysical investigation is expected to provide an overview of the technical data about the rock physical properties, the rock depth, and the distribution of rock layers in the investigated area [7].

One of the most widely used geophysical methods to explore underground resources is the geoelectrical resistivity approach. The main principle of the method is the fact that every type of soil and rock has an inherent difference in electrical properties, for example, different materials and minerals pose unique electric resistivity values (specific resistivity) that can be measured [8]. This characteristic does not only rely on their mineral compositions, but also the water content, salt concentration, and more. Unconfined sediment generally has a smaller value of resistivity compared with compacted sedimentary rocks. Meanwhile, igneous rocks have a much higher resistivity value. The value gets decreased if the rocks contain water with a high salt concentration. Moreover, metamorphic rocks even have higher resistivity than igneous rocks, which clearly demonstrate that the obvious difference in electrical properties between different materials can be measured from a geoelectric approach. Further, the variation of resistivity in a particular type of rock may depend on the vertical and lateral distribution of the rock [9]. In the geoelectrical resistivity method, we supply electrical current into the ground using two metal electrodes while two axes are placed to measure an electrical potential difference between different measurement points. The method still works with either direct current or low-frequency alternating current flow into the earth. We use apparent resistivity as a common term for the measured resistivity in real life when we referred to resistivity value [10].

The geoelectric resistivity method has been used in various studies of geophysical surveys in Indonesia, for example, Islami et al. used the resistivity approach for investigating groundwater in peatland in Riau, Indonesia [11]. Further, a study by Supriyadi et al., also utilized such a geoelectric method to analyze seawater intrusion into groundwater sources in Semarang, Indonesia [12]. On the other hand, Rusydy et al. were able to utilize VES data to study sediment characterization Krueng Aceh basin, Indonesia [13].

In this study, we performed a geoelectric resistivity survey to explore and interpret the existence of groundwater sources such as aquifers in the karst area in Gunung Kidul regency known as the Gunungsewu karst area [4,14]. The mountain was formed as a result of abrasion and uplifting process, indicated by the presence of joints in the layer of limestones. When rain falls, some water vanishes into a sinkhole, penetrates the joints, and dissolves the walls of limestone. On the other hand, another karst area also exists in the coastline of Parangtritis beach marked by the formation of limestone cliffs in the eastern part of the beach. This formation is well exposed in the Wonosari area and its surroundings, with a thickness of more than 800 meters, which is dominated by carbonate rocks consisting of layered limestones and reef limestones [15].

2. Methodology

2.1. Observation area
The research was carried out in Eroniti Conservation Park (Taman Kehati Eroniti), Ponjong district, Gunung Kidul regency, Yogyakarta. The area of the conservation is 10 hectares, according to measurement by delineation map, which is allocated for a green open space in the region. The conservation park is surrounded by ten mountains. Nine of the mountains are designated for wildlife conservation and karst ecosystem in Gunungsewu, Gunung Kidul regency. The acquisition design in the are is shown in Figure 1.
2.2. **Tools and Equipment**

The main tools and the equipment utilized for the groundwater exploration in the survey area is listed as follows:

1. IRIS SYSCAL Resistivity Meter
2. 12 Volt Accu
3. 4 electrodes (2 direct electrodes and 2 potential electrodes)
4. 250-meter AB electric cable and 250-meter MN cable
5. Multimeter Fluke 189

2.3. **Work method of the geoelectric approach**

There were six different measured VES points installed using Schlumberger configuration spread throughout the observed area. The configuration, as shown in Figure 2, is the most common electrode configuration for the geoelectric measurements, which is widely applied for various geological and mining purposes. The measurement point (VES point) is denoted as O; A and B are current electrodes;
M and N are potential electrodes, and a is the penetration depth. The geometric factor (Ks) in Schlumberger configuration is computed from field measurements using the relation: \( r = \frac{AB}{2} \), m is MN /2. The measurements are performed within a range of AB/2 value and then from that, we compute rho. The rho values are plotted with respect to AB/2 to obtain a field curve. From the observed data, data analysts create predicted curves on the semi-log sheets with a scale of 62.5 mm/cycle. The predicted curve obtained from each VES point is compared with the actual curve according to the resistivity values of the rocks on the base plate to determine the condition of rock formations below the ground surface. Computing the resistivity and thickness of rock layers is performed using geoelectric interpretation via Barnes resistivity layer, meanwhile, the groundwater prediction uses an electrical logging program [16]. From the interpretation result, we determine the thickness of every rock layer in the survey points according to their resistivity value. Therefore, we can predict the existence of rock formations around the observation region that contain water inside.

Geoelectric methods attempt to measure the resistivity value for each layer according to the field curve formulated above, and also obtain the actual resistivity along with the thickness of each layer on different sounding points. Within the geoelectric interpretation, measuring the actual resistivity using the anisotropy concept and generating a log of the resistivity to identify the existence of layers of water-bearing rocks below the ground surface. The next step is to use the Curve Matching method, which is a trial-and-error concept to compare the curve fields obtained from resistivity and depth level. IP2WIN program is used to cross-check the results. The program employs Resistivity Transform: a direct resistivity interpretation, which is arranged using filters from Ghosh [17]. In brief, we utilized the following steps for the geoelectric resistivity method in our study:

1. We determined the placement of VES points in the area.
2. The resistivity measurement in each point using a unit of IRIS SYSCAL Resistivity Meter.
3. The data analysis and data interpretation using geological analysis based on the electrical properties of rocks.

3. Result and Discussion
Using the setup from the previous section, geoelectrical measurements of the six VES (Vertical Electrical Sounding) points had been carried out and were divided into 4 paths. The reconstructed cross-section from geoelectric data was based on the order of the vertical resistivity or resistivity that is below the ground surface. Interpreting the types of rock layer was performed based on corrections and correlations with existing data of the surface geology as well as the obtained resistivity value of the rock layer itself. After the data interpretation, we obtained that the rock layers at some VES point can be grouped into several types of layers along with the depth and thickness obtained from the resistivity value. Next, in this section, we further discuss the result of the resistivity analysis and its interpretation for each VES point.

3.1. Interpretation of measured resistivity for different VES points
For each point, we obtained both graphical and tabular output (Figure 3 and Table 1-6) from IP2WIN software. The graphs in Figure 3 are called log resistivity curves in which the Y-axis is the measured resistivity value with logarithmic scaling, and the X-axis is AB/2 (i.e., a half distance between two current electrodes) in meters. The curves provide a one-dimensional representation of the field data interpretation. Meanwhile, the tables give information about the rock layer based on the resistivity measurements.

3.1.1. Point 1
At point 1, there was an indication of some anomaly in resistivity value that was marked by a very low Rho value (37.1 Ohm.m) between two vertical levels (26.4 m to 49.4 m) with a thickness of ± 23 m (see Table 1 and Figure 3a). This may indicate the existence of a groundwater source, which is further interpreted in limestone lithology as the probable existence of perched aquifers.
Figure 3. Resistivity curves obtained from all VES points
(x-axis: length (m) and y-axis: rho (ohm.m))
Table 1. The profile of geoelectric measurement at point 1

| From (m) | To (m) | Rho (Ohm.m) | Lithology                  |
|---------|--------|-------------|---------------------------|
| 0       | 0.6    | 21.4        | Soil (Ground effect)      |
| 0.6     | 2.41   | 10.2        | Mediterranean soil         |
| 2.41    | 4.43   | 13.3        | Layered limestone          |
| 4.43    | 26.3   | 4676        | Perched aquifer (Caliche)  |
| 26.4    | 49.4   | 37.1        | Layered limestone (Diffuse)|
| 49.4    | 166    | 980         | Underground river          |
| 166     |        | 443         |                           |

3.1.2. Point 2

We also found an indication of a low resistivity value at point 2 due to anomaly, namely at a value of 122 Ohm.m from Table 2 and Figure 3b. The anomaly was observed at a depth of 166 m, which may be the presence of confined aquifers or an underground river in the karst (limestone) environment. The thickness of that layer was unable to measure because at that level the measurement equipment already achieved the maximum depth limit.

Table 2. The profile of geoelectric measurement at point 2

| From (m) | To (m) | Rho (Ohm.m) | Lithology                  |
|---------|--------|-------------|---------------------------|
| 0       | 0.6    | 45.7        | Soil (Ground effect)      |
| 0.6     | 5.28   | 11.8        | Mediterranean soil         |
| 5.28    | 11.9   | 25.2        | Mediterranean soil         |
| 11.9    | 95.7   | 4625        | Layered limestone          |
| 95.7    | 166    | 1129        | Layered limestone (Diffuse)|
| 166     |        | 122         | Underground river          |

3.1.3. Point 3

There was no significant drop in resistivity values found in the rock layers at point 3 as shown in Table 3 and Figure 3c. The high values, ranging from 5800-9800 Ohm.m, were interpreted simply as limestone layers.

Table 3. The profile of geoelectric measurement at point 3

| From (m) | To (m) | Rho (Ohm.m) | Lithology                  |
|---------|--------|-------------|---------------------------|
| 0       | 0.6    | 27          | Soil (Ground effect)      |
| 0.6     | 4.1    | 12.2        | Mediterranean soil         |
| 4.1     | 166    | 9891        | Layered limestone          |
| 166     |        | 5829        | Layered limestone          |
3.1.4. Point 4
At point 4 there was no indication of an anomaly in resistivity values that can prove the existence of aquifers, since the apparent values tend to be large, ranging from 9200-11200 Ohm.m (see Table 4 and Figure 3d). The large resistivity value is interpreted as a limestone layer. However, there was a suspicious value of 9.16 Ohm.m at an elevation of 3 – 13 m. It is possible that at this depth level there is weathering of limestone (Mediterranean soil with water seepage).

Table 4. The profile of geoelectric measurement at point 4

| From (m) | To (m) | Rho (Ohm.m) | Lithology                |
|---------|--------|-------------|--------------------------|
| 0       | 0.6    | 37.9        | Soil (Ground effect)     |
| 0.6     | 3.55   | 14.1        | Mediterranean soil        |
| 3.55    | 13.2   | 9.16        | Mediterranean soil        |
| 13.2    | 166    | 9258        | Layered limestone         |
| 166     |        | 11289       | Layered limestone         |

3.1.5. Point 5
The measurement at this point summarized in Table 5 and Figure 3e was quite similar to that of point 4 where the resistivity value tends to be large, ranging from 9200-15000 Ohm.m. This may be interpreted as limestone layers. Further, there was also a suspicious value of 7.77 Ohm.m, which is similar to point 4 because the location of the two points is close to each other.

Table 5. The profile of geoelectric measurement at point 5

| From (m) | To (m) | Rho (Ohm.m) | Lithology                |
|---------|--------|-------------|--------------------------|
| 0       | 0.6    | 33.8        | Soil (Ground effect)     |
| 0.6     | 4.68   | 14.8        | Mediterranean soil        |
| 4.68    | 11.2   | 7.77        | Mediterranean soil        |
| 11.2    | 166    | 9262        | Layered limestone         |
| 166     |        | 15506       | Layered limestone         |

3.1.6. Point 6
The measurement at point 6 (see Table 6 and Figure 3f) shows that there was an anomaly at a depth of 68.9 m to 166 m in which the resistivity is between 23 – 96 Ohm.m. The lithology of the limestone suggests the presence of confined aquifers or some underground river.
Table 6. The profile of geoelectric measurement at point 6

| From (m) | To (m) | Rho (Ohm.m) | Lithology          |
|----------|--------|-------------|--------------------|
| 0        | 0.6    | 23.3        | Soil (Ground effect) |
| 0.6      | 12.3   | 15.5        | Mediterranean soil |
| 12.3     | 68.9   | 1033        | Layered limestone  |
| 68.9     | 166    | 96.8        | Aquifers           |
| 166      |        | 23.3        | Underground river   |

3.2. Two and three-dimensional visualization of the results

All measurements from those VES points (Figure 3) were then interpolated between points to obtain a 2- and 3-dimensional image profiles in accordance with Figure 4 where in general this area consists of Mediterranean soil resulting from weathered limestone, and limestone lithology. The aquifers found were of 2 types, namely, perched aquifers at a depth of 27 m at point 1 and confined aquifers at a depth of 166 m at point 2 and 6 as seen at right below corner of figure 4.

Figure 4. Two- and three-dimensional representation of the geoelectric interpretation
4. Conclusion
This study had investigated the groundwater source exploration in the Karts area in Ponjong region using the geoelectrical resistivity method from the six different VES points. Our results show that the area generally consists of Mediterranean soil resulting from weathered limestone, and limestone lithology. The aquifers found in the area were of two types, namely, perched aquifers at a depth of 27 m at point 1 and confined aquifers at a depth of 166 m at 2 and 6. From the results of the groundwater survey using a geoelectric approach, it is recommended for the next step to add two more VES points around the water wells owned by local residents who live nearby because it can provide a comparison of the results before and after well drilling. We can employ machine learning approaches to compare the field data in different scenarios for forecasting the existence of water-bearing rocks using existing field data [18].

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