Geoelectrical survey and cone penetration test data for groundwater potential determination around Gatot Subroto Street, Banjarmasin

Muhammad Archie Antareza¹, Abdurrahman Wafi², Yudi Lasmana³, and Mariyanto Mariyanto¹,⁎
¹Department of Geophysical Engineering; Faculty of Civil, Planning and Geo Engineering; Institut Teknologi Sepuluh Nopember, Surabaya 60111, Indonesia.
²PT. Andalan Tunas Mandiri, Jakarta 13940, Indonesia
³Balai Penelitian dan Pengembangan Rawa, Kementrian PUPR, Banjarmasin

⁎Email: mariyanto@geofisika.its.ac.id

Abstract. Subsurface condition evaluation is often relied to answer various necessities in a community, such as groundwater potential determination as a source of water supply. One of the most utilized method for this purpose is the geoelectrical method due to its efficiency, cost effectivity, and non-invasive nature. Geoelectrical method can also be used in tandem with geotechnical method, such as the Cone Penetration Test (CPT). In this study, a geoelectrical survey has been conducted in Gatot Subroto Street, Balikpapan. The survey uses 3 geoelectrical configurations: Dipole-Dipole, Wenner-Alpha, and Wenner-Schlumberger, which was performed using MAE type X-612EM+ with 24 electodes and 2 m spacing between electrodes. Soil quality assessment has also been conducted at the location from 0 to 29 m of depth using CPT. After geoelectrical survey had been done, the data would then be interpreted along with CPT data to project subsurface condition around the studied location. Based on the observation of the geoelectrical survey up to 6 m of depth, there are areas showing low resistivity value of <100 Ωm, characterizing that the layer is dominated by clay. In addition, groundwater potential is also found at a depth of ±2 m and characterized by a very low resistivity value of < 1.7 Ωm. Furthermore, CPT data classifies the soil layer from 0 to 19.40 m as very soft clay. These results infer strong correlation between geoelectrical and CPT data at the observed location.

1. Introduction
The supply of resources is one of the common problems to sustain the life in a community; one of such is water supply. However, many of these essential commodities, especially groundwater, can be found beneath the ground. While these underground resources are unable to be searched directly through surficial observations, numerous techniques were invented to answer this challenge. Geophysical methods are among these techniques, which assess subsurface condition through the observation of physical property variations (e.g. density, magnetic susceptibility, resistivity, etc.) on an area [1,2]. These methods are popularly used due to its efficiency, cost effectivity, and non-invasive nature.
In the case of determining groundwater potential, the preferable geophysical method to use is the geoelectrical method [3,4]. Geoelectrical method is a geophysical method that involves high-voltage DC current injection through the ground by a pair of current electrodes and measuring the potential difference received by a pair of potential electrodes [1]. Based on the injected current and potential difference values, the variation of resistivity on subsurface rock layers can be determined. The resistivity variation values are plotted as a 2D cross-section and then used to predict the materials underneath the surface of the surveyed area.

Other techniques that can be used to assess subsurface condition are the geotechnical methods. On the contrary to geoelectrical methods, these methods are invasive, costly, and time-consuming. However, these methods are proven to be more accurate than geoelectrical methods as they involve direct tests on samples from the area of interest [5–7]. In order to exploit the advantages of both methods, the combination of geoelectrical methods and geotechnical methods have begun to be employed in different studies and applications [8–12]. An example of such combination is geoelectrical method with Cone Penetration Test (CPT). CPT is a geotechnical method that measures the penetration resistance of soils in response to a tool with conical tip pushing the ground. While this method is typically used for soil quality assessment, it has also recently been involved in groundwater exploration [13]. In this paper, geoelectrical data was interpreted along with Cone Penetration Test (CPT) data to determine groundwater potential.

2. Methodology

The urgency of this paper arises from the construction of a new building which requires the potential of groundwater to be located. The study site is situated in Gatot Subroto Street, Banjarmasin, South Kalimantan. Based on Banjarmasin’s geological map [14], the area of study is dominated by pebble, sand, silt, clay, and mud. Geoelectrical survey was performed in the study area using IP Meter MAE type X-612EM+. A 2D profile was surveyed with profile length of 48 m with 24 electrodes and 2 m spacing between electrodes, as shown in Figure 1(b). The survey used 3 geoelectrical configurations: Dipole-Dipole, Wenner-Alpha, and Wenner-Schlumberger.

The acquired data was processed using ZondRes2D software. ZondRes2D is a geoelectrical data processing software that converts apparent resistivity values (as electrode spacing function) to true resistivity values (from electrode spacing function to depth function). It is also known that in 2017, soil quality assessment has been conducted at the location from 0 to 29 m of depth using CPT. After the geoelectrical survey had been done, the data would then be interpreted along with CPT data to predict the subsurface condition around the studied location. A systematic and simple description of the methodology is shown in Figure 1(a).

It is known that CPT has been conducted around the new building, 2 m to the left of the geoelectrical survey line. In order to determine the soil type in the location, this test involves vertically penetrating the soil surface at regular intervals using an instrument called cone penetrometer. The cone penetrometer then measures penetration resistance at its tip and friction at its shaft. The data from this measurement is compiled and interpreted corresponding to the CPT data values.
3. Results

3.1. Result of geoelectrical survey

The geoelectrical survey resulted in 3 different cross-sections representing the configurations that were used, which are Dipole-Dipole configuration, Wenner-Alpha configuration, and Wenner-Schlumberger configuration. Each configuration groups consist of three different cross-sections: Observed apparent resistivity (Figure 2 (a), 3 (a), and 4 (a)), calculated apparent resistivity (Figure 2 (b), 3 (b), and 4 (b)), and true resistivity (Figure 2 (c), 3 (c), and 4 (c)). Observed apparent resistivity cross-section is resulted by the acquired resistivity values, while calculated apparent resistivity is generated by finite element algorithm used by ZondRes2D software. Inversion process is then performed using these resistivity cross-section which results in the true resistivity cross-section. True resistivity cross-section is the simplified model section of subsurface condition used for interpretation. In general, there are 3 different types of distinguished “layers” classified based on their respective resistivity values. The first layer is represented by orange-violet coloured area with resistivity values of > 32.5 Ωm, which is the highest value amongst the layers. The second layer is represented by light green-yellow coloured area with resistivity values of 5-32.5 Ωm. The third layer is represented by dark blue-light blue coloured area with resistivity values of 1-5 Ωm.

On the survey using Dipole-Dipole configuration (Figure 2), orange-violet area seems to be grouped into 7 clusters. On the other hand, dark blue-light blue area form two clusters with varying thickness. Meanwhile, the light green-yellow area are unclustered and tend to spread all over the cross-section. The details of resistivity value distribution is further shown by Table 1.
Figure 2. (a) Observed apparent resistivity, (b) calculated apparent resistivity, and (c) true resistivity 2D vertical cross-section of Dipole-Dipole geoelectrical configuration

| Color (Resistivity Value)                  | Cluster no. | Distance | Depth    |
|-------------------------------------------|-------------|----------|----------|
| Orange-Violet (>32.5 Ωm)                 | 1           | 3-11 m   | 0-2 m    |
|                                           | 2           | 11.5-13.5 m | 0-1 m    |
|                                           | 3           | 24-27.5 m | 2-5 m    |
|                                           | 4           | 28.5-29.5 m | 0-1 m    |
|                                           | 5           | 31.5-35 m | 0-1 m    |
|                                           | 6           | 37.5-41 m | 0-1 m    |
|                                           | 7           | 35-43 m   | 3-11 m   |
| Light green-Yellow (5-32.5 Ωm)           | Spread all over the cross-section (Unclustered) |
| Dark blue-Light blue (1-5 Ωm)            | 1           | 3-10 m   | 3-5.5 m  |
|                                           | 2           | 10-25 m  | 1-3.5 m  |
|                                           | 3           | 27-31 m  | 1-5.5 m  |
|                                           | 4           | 31-43 m  | 1-2 m    |

Table 1. Resistivity value clusters and their locations for Dipole-Dipole configuration

On the survey using Wenner-Alpha configuration (Figure 3), orange-violet area area are grouped into 3 clusters instead. However, one of the clusters tend to spread and envelop a dark blue-light blue area at a distance of 29.5-43 m. Similar to Dipole-Dipole, the dark blue-light blue area in this configuration also form two huge clusters, but with different thickness. It can also be seen that the thickness of the dark blue-light blue area of this configuration are more evenly distributed than in Dipole-Dipole. Unlike Dipole-Dipole, however, the light green-yellow area now tend to envelop both of the previous area instead of spreading all over the cross-section. The details of resistivity value distribution is further shown by Table 2.
Figure 3. (a) Observed apparent resistivity, (b) calculated apparent resistivity, and (c) true resistivity 2D vertical cross-section of Wenner-Alpha geoelectrical configuration

Table 2. Resistivity value clusters and their locations for Wenner-Alpha configuration

| Color (Resistivity Value) | Cluster no. | Distance  | Depth  |
|---------------------------|-------------|-----------|--------|
| Orange-Violet (>32.5 Ωm)  | 1           | 3-14 m    | 0-2 m  |
|                           | 2           | 17.5-20.5 m | 0-1 m  |
|                           | 3           | Spreads at distance 24-43 m |        |
| Light green-Yellow (5-32.5 Ωm) | Spread all over the cross-section (Unclustered) | |
| Dark blue-Light blue (1-5 Ωm) | 1           | 3-22.5 m  | 2-7 m  |
|                           | 2           | 31-43 m   | 2-7 m  |

Lastly, on the survey using Wenner-Schlumberger configuration (Figure 4), orange-violet area are grouped into 3 clusters with similar locations to Wenner-Alpha, with one of the clusters spreading and enveloping the dark blue-light blue area at a distance of 30.5-43 m. However, the “centers” of the cluster appear more violet than in Wenner-Alpha. In addition, the dark blue-light blue area in this configuration also form two huge clusters, but with similar, but less even, distribution of thickness to Wenner-Alpha configuration. Similar to Wenner-Alpha, however, the light green-yellow area now tend to envelop both of the previous area instead of spreading all over the cross-section. The details of resistivity value distribution is further shown by Table 3.
Figure 4. (a) Observed apparent resistivity, (b) calculated apparent resistivity, and (c) true resistivity 2D vertical cross-section of Wenner-Schlumberger geoelectrical configuration

Table 3. Resistivity value clusters and their locations for Wenner-Schlumberger configuration

| Color (Resistivity Value) | Cluster no. | Distance     | Depth      |
|---------------------------|-------------|--------------|------------|
| Orange-Violet (>32.5 Ωm)  | 1           | 3-14 m       | 0-2.5 m    |
|                           | 2           | 16-22.5 m    | 0-1.5 m    |
|                           | 3           |              | Spread at distance 26-43 m |
| Light green-Yellow (5-32.5 Ωm) | Spread all over the cross-section (Unclustered) |
| Dark blue-Light blue (1-5 Ωm) | 1           | 5-23 m       | 3-7 m      |
|                           | 2           | 33-42 m      | 2.5 m      |

3.2. Cone Penetration Test (CPT) data
Soil quality assessment has been conducted in the study area using Cone Penetration Test (CPT). The test is highlighted in the following table:

Table 4. CPT data per depth and their respective classifications

| Depth       | Description | Classification |
|-------------|-------------|----------------|
| 00.00 – 19.40 | Clay       | Very Soft     |
| 19.40 – 26.00 | Clay       | Soft          |
| 26.00 – 29.20 | Clay       | Medium        |

Based on the CPT data (Table 4), it was found that the study area is dominated with clay structures with 3 classifications. Very soft clay structure is found at a depth of <19.40 m, soft clay structure is found at a depth of 19.40-26 m, and medium clay structure is found at a depth of 26-29.20 m.

4. Discussion
The geoelectrical results are classified into 3 different layers based on their respective resistivity value range. Resistivity values can be used to predict materials beneath the surveyed site using a guideline based on literatures, as demonstrated in Table 5 [1]. The main focus of this paper, however, is only in...
distinguishing clay and groundwater. Based on Table 5, clay has a resistivity range of 1-100 Ωm and groundwater has a resistivity range of 0.5-300 Ωm. Although both materials’ resistivity range intersect, it can be inferred naturally that groundwater has a lower resistivity than clay. When taking this knowledge into account, interpretation of these 3 different layers can be determined.

Table 5. Resistivity values of different materials [1]

| Material   | Resistivity (Ωm) |
|------------|------------------|
| Limestones | 500 – 10,000     |
| Sandstones | 200 – 8,000      |
| Shales     | 20 – 2,000       |
| Sand       | 1 – 1,000        |
| Clay       | 1 – 100          |
| Groundwater| 0.5 – 300        |

The dark blue-light blue layer (1-5 Ωm) corresponds to groundwater, the orange-violet layer (>32.5 Ωm) corresponds to “dry” clay, and the light green-yellow layer (5-32.5 Ωm) corresponds to “wet” clay with transitioning water saturation (lower resistivity corresponds to higher water saturation of clay). By comparing the 2D vertical cross-section results of Dipole-Dipole, Wenner-Alpha, and Wenner-Schlumberger configuration, distribution of resistivity values varies between all configurations. However, it is apparent that all configurations signalizes a groundwater potential at a depth of 2-7 m in two locations: at a distance of 3-22.5 m and 31-43 m.

CPT data alone cannot be used to determine the overall subsurface materials of the surveyed area. However, it can help to confirm geoelectrical data result through assessing soils’ penetration resistance. Based on CPT data (Table 4), very soft clay structure is identified at a depth of 0-19.40 m. Very soft clay structure correlates to the geoelectrical data interpretation that the surveyed area is dominated by groundwater and wet clay. Very soft clay on CPT data and wet clay on geoelectrical data refer to sandy clay, which has a higher porosity than regular clay and allows the layer to be soaked with water [14]. The groundwater system itself is suspected to be a confined aquifer as the groundwater is surrounded by relatively impermeable layers [15]. Hence, CPT data confirms the existence of groundwater in the area.

5. Conclusion

The interpretation of geoelectrical data found that the area is classified into 3 layers: groundwater, wet clay, and dry clay. It is predicted that the area is mostly comprised of wet clay and groundwater at a depth up to 10 m, while the classification of CPT data suggests that the area is dominated by soft clay at a depth up to 19.40 m. Based on the correlation of geologic information, resistivity data interpretation, and CPT data classifications at different depths, it can be concluded that there is groundwater potential at a depth of 2-7 m in two locations: at a distance of 3-22.5 m and 31-43 m.

Acknowledgements

Our team would like to show sincerest appreciation to Balai Litbang Rawa, Banjarmasin, PT. Andalan Tunas Mandiri for conducting the geoelectrical survey and lending the software license. We also would like to thank Institut Teknologi Sepuluh Nopember (ITS) and Geophysical Engineering ITS for giving support, funding, and guidance during this research so this paper can be finished properly.
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