Electrical resistivity survey for groundwater investigation in Padalarang, West Java

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Abstract. An electrical resistivity survey has been carried out in Padalarang, West Java, to investigate groundwater potential to solve the lack of clean water. The survey consists of three vertical electrical sounding (VES) and four electrical resistivity tomography (ERT) profiles in the study area. The data was processed using inversion method. Wells in the area is available to validate resistivity data. The result of VES shows a low resistivity value (2.82 - 11.72 Ωm) at its fourth layer, which we expected to be a zone with high water content. ERTs result also revealed a low resistivity value (<10.1 Ωm), approximately more than 60 m depth at ERT 3 and 4. We expect this low resistivity zone to have a groundwater potential. A low resistivity zone in the central part of the study area may yield a high groundwater potential. Our result could serve as a guide to engineers for planning on sitting boreholes either for domestic, agricultural, or industrial use.

Keywords: Padalarang, VES, ERT, low resistivity zone, groundwater potential

1. Introduction
Water is essential for humans to live, and one of the safest kinds of water supply is groundwater. Minor water treatment is required for groundwater since it has natural protection against pollution by the covering layers [1]. Lack of access to appropriate water quality for domestic, agricultural, and industrial uses is one of the major limiting factors to socioeconomic development.

West Java has the highest population density in Indonesia, with 18% of the Indonesian population living there. The dry season in West Java always brings drought disasters leading to a lack of clean water for the local community. The main problem of the clean water crisis is the lack of infrastructure to manage or find a new source of clean water. In addition, the amount of population and demand for potable water for domestic, agriculture, and industrial uses in West Java also have increased rapidly.

The resistivity survey is well-known in groundwater studies [2] because of its simplicity, low-cost technique, and efficiency in areas with high contrasting resistivity [3]. We measured ground resistivity by injecting currents between one electrode pair and measured the resulting potential differences at the surface between another electrode pair. Commonly, we apply the one-dimensional vertical electrical sounding (VES) technique to investigate groundwater resources [4]. In some cases, we apply the two dimensional electrical resistivity tomography (ERT) technique where lateral changes or heterogeneity in resistivity exist [5]. Both methods to investigate groundwater resources are recently applied successfully rather than the VES stand-alone technique [6]. The objective of this study is to apply an integrated geoelectrical approach (VES, ERT) to investigate groundwater potential in West Java.
We located the study area in the sub-district of Padalarang, 20 km from the capital of the province of West Java (figure 1). There were four wells available in this area prior to the previous survey. The area was characterized mainly by heavily forested terrain, while the local community used some of the north parts as a farming field.

![Figure 1. Location of the investigated area.](image)

2. Material and methods
The field resistivity acquisition used in this survey was the ARES II equipment with an array of 48 electrodes. The ARES II system is computer-controlled with direct reading of the apparent resistivity of the grounds in ohm digitally by its LCD monitor. The position of the electrodes was oriented perpendicular to the ground surface to keep signal distribution.

A total of 3 VES by applying Schlumberger array were carried out in the studied area (figure 2,) with the distance between the two current electrodes starting from 2 meters and reaching a maximum of 360 meters. We processed the measured apparent resistivity data by the inversion technique to determine each layer’s true resistivity and thickness. In this work, we used MATLAB software to produce depth-sounding curves and inversion of VES data for computer modeling. The algorithm optimizes the fit between the observed and the calculated apparent resistivity data. We initialized the procedure by user-selected initial model parameters and employed the damped least-squares solution with the Singular Value Decomposition (SVD) technique for inversion [7].

ERT data acquisitions also used the Schlumberger array with four lines, which intersect each other (figure 2). ERT 1 and ERT 2 have electrode spacing of 7.5 m and 330 m in length, while ERT 1 and ERT 2 have electrode spacing of 10 m and 430-440 m in length. The acquired resistivity data were then inverted based on the smoothness-constrained least-square method with Res2Dinv software from Geotomo [8]. We added topographic data due to the significant elevation of each profile. We used the root mean square (RMS) value to determine the fitness between observed and calculated data.
3. Results
Figure 3 shows the results obtained from VES. Curve type obtained from VES curves revealed a 4-layer with HK type ($\rho_1 > \rho_2 < \rho_3 > \rho_4$). Generally, the RMS value in VES inversion has a relatively low value. Wells in this area were available to correlate the lithological of each layer. Table 1 shows the interpretation of VES combined with wells lithological information.

The result of VES indicate there are low resistivity zone at a depth of around 80 m in VES 3. We also observed the low resistivity value in VES 1 and VES 2 at a depth of around 123 m and 141 m, respectively. Available wells in this area are only limited to 20 m depth, so we could not interpret this low resistivity zone in terms of the lithological unit. We interpret this low resistivity zone (2.8 - 11.7 $\Omega$m) as the zone with high water content.

The ERT 1 (figure 4a), trending NW-SE, has Well 02 for calibration. We interpreted the top layer with moderate resistivity (40 $\Omega$m) as silty clay, while the second layer was relatively low (25.4 $\Omega$m), and we interpreted it as saturated gravelly clay. These two lithological variations fitted well with Well 02 information, where saturated gravelly clay was probably due to irrigation. We interpreted the zone below the Well bottom with high resistivity (64 $\Omega$m) as andesite breccia.

We calibrated the ERT 2 data (figure 4b), trending W-E with Well 1 data. In Well 01, we identified three distinct lithological units (figure 3d). ERT 2 results show clearly that this distinct lithological unit with silty clay has a resistivity value of 25.4 $\Omega$m, gravelly clay has a resistivity value of 32 $\Omega$m, and andesite breccia characterized by a resistivity value of 40.3 $\Omega$m. The higher resistivity means an increase in compactness and fresh andesite breccia. The VES-02 at 160 m shows below this profile around 140 m in depth reveals a low resistivity zone indicating potential groundwater occurrence. Unfortunately, the ERT 2 could only reveal approximately 50 m depth from the surface.
Figure 3. Sounding curves of a) VES-01, b) VES-02, and c) VES-03. d) Wells with lithological information.

Table 1. Interpretation of each layer in VES curves.

| VES point | Layer | Resistivity (Ωm) | Thickness (m) | Depth (m) | Lithology | RMS (%) |
|-----------|-------|------------------|---------------|-----------|-----------|---------|
| 01        | 1     | 27.81            | 1.91          | 0 - 1.91  | Silty clay | 2.06    |
|           | 2     | 17.10            | 11.90         | 1.91 - 13.81 | Gravelly clay |          |
|           | 3     | 41.88            | 109.88        | 13.81 - 123.69 | Andesite breccia | |
|           | 4     | 10.62            | ∞             | 123.69 - ∞ | High water content zone | |
| 02        | 1     | 25.86            | 2.16          | 0 - 2.16  | Silty clay | 1.87    |
|           | 2     | 17.14            | 3.54          | 2.16 - 5.7 | Gravelly clay |          |
|           | 3     | 39.60            | 135.38        | 5.7 - 141.08 | Andesite breccia | |
|           | 4     | 11.72            | ∞             | 141.08 - ∞ | High water content zone | |
| 03        | 1     | 67.22            | 1.15          | 0 - 1.15  | Silty clay | 3.41    |
|           | 2     | 25.18            | 18.67         | 1.15 - 19.82 | Gravelly clay | |
|           | 3     | 99.66            | 59.99         | 19.82 - 79.81 | Andesite breccia | |
|           | 4     | 2.82             | ∞             | 79.81 - ∞ | High water content zone | |

Unlike ERT 1 and ERT 2, ERT 3 was trending S-N (figure 4c), which has a better depth of investigation due to greater length. We observed a significant resistivity variation in both near-surface and at greater depth. This variation was probably due to the high location that could lead to noise. Three wells (Well 03, Well 04, and Well 02) are located in this profile to help interpret resistivity results. At a distance of 280 - 320 m, we observed a low resistivity zone (6.35 Ωm) at a depth of 10 - 25 m. We interpreted this zone as a water accumulation. Such zone we also observed at a distance of 240 - 280 m at a depth greater than 60 m. The water accumulation probably flows through the
permeable layer and is stored at a depth greater than 50 m. We observed that the permeable layer was probably gravelly clay at Well 02. VES-01, located at a distance of 210 m, also shows a low resistivity value (10.6 Ωm) at a depth greater than 100 m. We interpreted this low resistivity value to have groundwater potential. We interpreted Andesite breccia as an impermeable layer to hold this accumulated water.

Figure 4. Result and interpretation of ERT profile for a) ERT 1, b) ERT 2, c) ERT 3, and d) ERT 4.
Like ERT 3, ERT 4 also trends S-N and shows a similar pattern (figure 4d). There is no well to calibrate the resistivity result in this profile. Thus, we interpreted this profile using the other profiles. We observed a low resistivity value (10.1 Ωm) at a distance of 140 - 180 m at the top layer until a 15 m depth. The low resistivity value is probably due to high water content. This low resistivity zone was also observed at a distance of 180 - 240 m at a depth of 60 m until a maximum depth of ERT profile, probably due to high water content flowing from the top layer through a permeable layer to a greater depth of the profile. We interpreted the permeable layer as gravelly clay as all wells indicate that gravelly clay is always in the second layer. We found a low resistivity value (2.8 Ωm) at a depth of 80 m at VES-03 located at 240 m. This low resistivity probably accumulated at a depth of greater than 80 m and indicates groundwater potential.

The low resistivity zones observed in ERT 3 and ERT 4 lines indicate that the water flows from higher topography (ERT 4) to lower topography (ERT 3). This indication agrees with VES results where VES-03, located at a higher elevation, encountered low resistivity at 80 m depth, while VES-01 in lower elevation encountered low resistivity at more than 100 depth. We encountered a low-velocity zone in the central part of the study area, which may yield high groundwater potential.

4. Conclusion
This study used geoelectrical methods consisting of VES and ERT to investigate groundwater at Padalarang, West Java. We used available wells to validate in interpreting resistivity data. All VES results revealed four geoelectrical layers and indicated a low resistivity value (2.82 - 11.72 Ωm) at the fourth layer, which we expected to be the zone with high water content. The ERT result provides a lateral and vertical variation of this area also revealed low resistivity values (<10.1 Ωm) at ERT 3 and ERT 4, where the depth was approximately more than 60 m from the surface. We encountered low resistivity values in the central part of the study area, probably yielding a high groundwater potential.

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