Investigation of groundwater aquifer at Noborejo, Salatiga using Electrical Resistivity Tomography (ERT) and Vertical Electrical Sounding (VES) methods

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Abstract. Local Water Supply Utility (PDAM) of Salatiga, Indonesia planned to build three new wells to meet the needs for clean water and increase the number of customers in Salatiga. The plans for the construction of the new wells are located in Randuancir, Kumpulrejo and Noborejo Sub-Districts. The groundwater aquifer layer in Noborejo Village is detected using the Electrical Resistivity Tomography (ERT) method, while the determination of the depth of aquifer layer will be controlled by the results of Vertical Electrical Sounding (VES) data processing. 4 ERT lines and 4 VES points were acquired in 2017. The processing results showed that water-containing layer tends to have a lower resistivity value. In the study area, 2 types of aquifers were found, namely unconfined aquifer (usually exploited using dug wells), and confined aquifer which are generally located on the deeper depth. Unconfined aquifers were identified with a lower resistivity value than its surroundings (20-80 Ωm) with an average depth of 25 m on all lines. Whereas confined aquifer has a higher resistivity in the range of 90 Ωm. However, confined aquifers are only found with certainty in Line 1, while in other Lines the possibility of a confined aquifers existence is smaller.

1. Introduction
Salatiga Regency is located in Central Java, Indonesia and situated on northeastern flank of Mount Merbabu. With the increasing population nowadays [1], the demand for water needs is also increasing. Local Water Utility Supply (PDAM) of Salatiga continued to improve services to the community, especially to urban areas that lack clean water. These sub-districts are Kumpulrejo, Randuancir and Noborejo Sub-Districts, all of which are located in Argomulyo District. These three Sub-Districts often experience a shortage of clean water due to being in a fairly high area and thin layers basin. To overcome this shortage of fresh water, PDAM of Salatiga planned to build artesian wells in these three sub-districts.

Noborejo Village is located on the southern part of Salatiga Regency which is included on Salatiga Groundwater Basin (SGB). On groundwater basin, there are two kinds of aquifer, which are unconfined aquifer and confined aquifer. Aquifer is a large underground storage space for water. The rock layer which is served as aquifer had high permeability so that water can flow easily. Aquifer layer
can be detected by using geoelectricity methods or usually called by resistivity method. This method studied the difference of rock resistivity by determined resistivity change to depth. Resistivity method is a preferable geophysical technique for groundwater exploration, as the resistivity is inversely proportional to rock properties. The rock properties contained of many things, such as porosity, mineral content, and water saturation.

This research intended to estimate deep confined aquifer on Noborejo Village by using two resistivity methods which are Electrical Resistivity Tomography (ERT) and Vertical Electrical Sounding (VES). The positive results of this research can aid PDAM to know the location and the depth of confined aquifer to build artesian well. This hopefully can support Noborejo community of fresh water shortage.

2. Salatiga Groundwater Basin (SGB)
Salatiga Regency is located on two groundwater basin, western half is situated on Rawapening Groundwater Basin (RGB) and eastern half is situated on Salatiga Groundwater Basin (SGB). SGB is a groundwater basin with area of 85.29 km$^2$ and covering Semarang District, Salatiga District, and Boyolali District [2]. Geological formation (Figure 1a) of SGB consists of Kerek Formation (Tmk) Payung Formation (Qn), Merbabu volcanic stone (Qme), Sumbing’s Lava (Qls), and Basal Formation (Qba), respectively from oldest to youngest [3,4]. This basin is dominated by Merbabu Volcanic Deposits which is consisted of volcanic breccia, lava, tuff, and laharic breccia of Mount Merbabu. This formation is laid above Kerek Formation which is a basement that made a lateral boundary of SGB consists of impermeable claystone and siltstone.

The groundwater table of SGB (Figure 1b) had a depth range of 6 to 30 m [5, 6]. The groundwater was estimated to be shallower on lower topography and deeper on higher topography. The groundwater on southwestern area is deeper than the groundwater on Salatiga City. It showed that Salatiga City had overlaying lithology the shallowest, whereas the thickest overlaying lithology situated on southwestern area at around 29 m deep.

Figure 1. a) Geological map, b) Map of water table depth of Salatiga Groundwater Basin [5]
3. Research Methods

Geoelectricity method is a geophysical method that studies the nature of electric currents in the Earth and how to detect it on the surface of the Earth. It is including the measurement of potential, current, and electromagnetic fields that occur, both naturally and due to injection of currents into the Earth. Therefore, the geoelectricity method has many kinds, including self-potential, telluric currents, magnetotelluric, electromagnetic, induced polarization, and resistivity.

The method used is resistivity method. Each media has different properties to the electricity current through, depends on the media’s resistivity. In this method, an electric current is injected into the earth through two current electrodes and the potential difference that occurs is measured through two potential electrodes. From the results of current measurements and potential differences for each different electrode distance can then be reduced variations in the price of the type of resistance of each subsurface layer. Resistivity method itself can be separated into two kinds. First is Electrical Resistivity Tomography (ERT) which is mapping or 2D resistivity. The second is Vertical Electrical Sounding (VES) which is sounding or 1D resistivity.

3.1. Electrical Resistivity Tomography (ERT)
ERT measurement was using dipole-dipole configuration (Figure 2), which current electrodes and potential electrodes move together, so that the apparent resistivity value is obtained laterally (horizontally). The electrode spacing used is 20 meters. The dipole-dipole electrodes configuration has a geometrical factor of $K= \pi a x n(n+1)x(n+2)$ [7].

Measured resistivity data are plotted at points corresponding to the value of $n$ ($n = 1, 2, 3, 4, 5, 6$) with the indicated depth is apparent depth level, so that the contour variation of the resistivity can be made laterally and vertically in the direction of pseudo depth. The measurement using the space between the current electrode and the potential electrode which is getting wider will provide deeper subsurface geological information. Thus, this dipole-dipole configuration can be considered effective for use in mapping, both laterally and vertically.

![Figure 2. Electrodes configuration of ERT by dipole-dipole](image)

3.2. Vertical Electrical Sounding (VES)
VES is carried out to obtain information about the depth or thickness of rock layers from the vertical resistivity value, in order to get a complete geological picture below the surface. The difference in resistivity will be clearly seen in the determination of the depth of rock layers that have different resistivity. Observation stations are fixed, while the current electrodes and the potential electrodes are moved in accordance with the electrode spacing as Schlumberger configuration (Figure 3). The electrode spacing will determine the size of the geometry factor. Geometry factor of VES is $K= 2\pi a$ [7].
Data acquisition was held by making 4 ERT lines with an average length of 500 meters. At each line a VES point is also measured to help the interpretation of ERT so that the interpretation is more accurate. Both ERT and VES data were acquired by using Syscal Junior Instrument (Figure 4a). The distribution of ERT lines and VES points can be seen in Figure 4b.

There are 5 lines can be seen in Figure 4b, which should be only 4 lines. Line 1 cannot be used because the data is poor. This is due to the line got through an area which is covered with asbestos debris and landfill. ERT which in its implementation was injecting currents, will not be able to give good results if the medium is loose rock. Instead, measurements are taken with the name Line 1_1. Line 2 also deviates from the original plan. That is because Line 2 plan turned out to be passing the houses. For that the direction of Line 2 was changed as is done in the field.

4. Results and Discussion
Subsurface resistivity models will be obtained from ERT processing results. This resistivity models will be interpreted as geological condition of the line. Each rock has a certain range of resistivity. Based on the resistivity value, a groundwater aquifer model will be determined. Generally, igneous rocks have a high resistivity. Whereas, aquifer tends to have lower resistivity values. There are 2 types of aquifer, namely unconfined aquifer which usually exploited using dug wells due to the shallow depth, and confined aquifer which situated on the deeper depth and can be exploited using artesian wells.

Determination of the aquifer depth will be controlled by VES processing results. This is undertaken because the accuracy of ERT results for vertical variations is not as accurate as VES results. In this section, 2D resistivity model of each line and 1D resistivity model of each point will be showed. Analysis and interpretation is carried out by correlating them to the geological conditions of the research area.

The ERT of Line 1_1 has a length of 500 meters and N180°E direction. Point 1_2 is at a distance of 120 meters from the start of Line 1_1 (Figure 5). In this line, it is clearly seen that unconfined aquifer
is located at a shallow depth of about 20 meters. This layer is situated on the 240\textsuperscript{th} to 440\textsuperscript{th} meter. Confined aquifer is estimated to be at a depth of about 70 meters and only 230\textsuperscript{th} to 320\textsuperscript{th} meter. The indications shown are only the upper part, thus reducing the level of confidence. On the other hand, most of the model shows moderate to high resistivity values. This confirms that the study area is dominated by igneous rock.

The VES result of Point 1\_2 shows the resistivity value of 39.4 \(\Omega m\) at a depth of 28.8 meters. This resistivity value falls within the range of the aquifer resistivity value [8], but its 5.1 meter thickness indicates another possibility, namely claystone intercalation. At a depth of 34 meters there is a layer that is suspected as a confined aquifer with resistivity values of 94 to 98 \(\Omega m\) with volcanic breccia lithology. From the ERT and VES analysis, it was concluded that in Line 1\_1 the prospect of confined aquifer is located at 230\textsuperscript{th} meter to 320\textsuperscript{th} meter at a depth of 70 meters.

![Figure 5. 2D resistivity model of ERT Line 1\_1](image)

Line 2 has a length of 500 meters and N135\degree E direction. Point 2 is located at a distance of 300 meters from the start of Line 2 (Figure 6). As in Line 1\_1, unconfined aquifers with relatively low resistivity at Line 2 are found at a depth of about 20 meters. This layer is visible from 160\textsuperscript{th} meters to 460\textsuperscript{th} meters shown in blue color. Whereas the confined aquifer is indicated at a depth of about 75 meters on 300\textsuperscript{th} meter to 360\textsuperscript{th} meter. As with Line 1\_1, the indication of the confined aquifer at Line 2 is shown upper part only, thereby reducing the level of confidence. Moderate to high resistivity spotted on this line shows the dominance of igneous rock in the study area.

VES result of Point 2 shows 6 rock layers. Unconfined aquifer is found at a very shallow depth of 1 meter with a thickness of 22 meters. While at depth of 30 meters found a layer with a resistivity value of 126 \(\Omega m\). This layer which is only 5 meters thick is presumed to be a tuff intercalation, not a confined aquifer layer even though the resistivity value is within the range. Confined aquifer layer was found at a depth of 72 meters with a resistivity value of 130 \(\Omega m\). This confined aquifer is expected to have volcanic breccia lithology. ERT and VES analysis results show confined aquifer in Line 2 is situated at a depth of more than 75 meters.

![Figure 6. 2D resistivity model of ERT Line 2](image)

Line 3 has a length of 500 meters and N135\degree E direction. Point 3 is at a distance of 235 meters from the start of Line 3 (Figure 7). The ERT results show that unconfined aquifer at Line 3 is found to be about 30 meters from the 100\textsuperscript{th} meter to the end of the line. The unconfined aquifer has a relatively
lower resistivity value which is indicated by the blue color. ERT model shows that confined aquifer is not found on this line. At depths of more than 30 meters, resistivity values range from 200 Ωm to 400 Ωm. This resistivity value is within the range for igneous rock.

Like VES Point 2, VES Point 3 result indicates unconfined aquifer is located at a very shallow depth of 1 meter with a thickness of 29 meters. Whereas confined aquifer was found with a quite high resistivity of 152 Ωm at a depth of 134 meters. The high resistivity is caused by aquifer lithology in the form of volcanic breccia. ERT and VES analysis results on Line 3 show confined aquifers at depths of more than 130 meters.

Line 4 has a length of 520 meters and N135°E direction. Point 4 is located at a distance of 180 meters from the beginning of Line 4 (Figure 8). Unconfined aquifer is presumed at a depth of 25 meters and is visible at 100th meters to the end of the line based on ERT results. Unconfined aquifer is shown in blue color on the ERT model. Whereas confined aquifer is not detected in this line. At depths of deeper than 25 meters, igneous rocks were found which dominated the study area with high resistivity of 250 Ωm to 700 Ωm.

VES Point 4 also shows an unconfined aquifer with a very shallow depth of 1 meter with a thickness of 29 meters. Whereas confined aquifer was found at a depth of 94 meters with a resistivity of 110 Ωm. This resistivity shows that aquifer lithology is volcanic breccia. ERT and VES analysis results indicate that the confined aquifer is laid at a depth of more than 90 meters.

Line 1 to Line 4 shows the correlation between ERT and VES results on unconfined aquifer identification. Unconfined aquifers have a relatively low resistivity (20-80 Ωm) with a shallow depth, from 1 meter to 30 meters. Whereas confined aquifer was found in ERT results of Line 1 and Line 2 with quite high resistivity namely 94 Ωm to 130 Ωm. ERT Line 3 and Line 4 do not represent a confined aquifer, but it is still found at VES Point 3 and Point 4 with resistivity of 110 Ωm to 152 Ωm. Confined aquifer is presumed to be at a fairly deep and varied depth of 70 meters to 130 meters. High resistivity indicates aquifer lithology in the form of volcanic breccia. ERT and VES results also get a good correlation on dominated rocks on the area. High to very high resistivity (200-1500 Ωm) signified igneous rock which is dominating the research area.
5. Conclusions
The findings from this study have provided the suggestion for PDAM of Salatiga to support Noborejo community on fresh water shortage is to drill some artesian well on Noborejo Village. The depth of artesian well should be deeper than 70 meters. The drilling techniques of artesian well should be contemplated better, because the dominating lithology of research area is igneous rock which is generally had a great hardness and make it hard to drill.

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