Integrated survey to identify potential groundwater aquifers in Jabung an Semarang using geoelectric and microtremor methods

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Abstract. The morphology of the Jabungan Village area has relatively steep land conditions. In lithology, this area has a layer of soil composed of sandstone, claystone, and limestone. Based on direct observations in the field, it was found difficult to obtain clean water that could be used for consumption. The water available and used by the majority of residents is shallow well water, which is not of very good quality. There is only one deep well with a depth of 68 meters but according to residents, the water that is channeled to these houses smells unpleasant and feels oily. To detect the potential of ground water in this area, the geoelectric method is integrated using the microtremor method. Geoelectric measurements were made at 3 location points while microtremor measurements were carried out at 9 location points. Based on geoelectric resistivity and microtremor measurements, it can be concluded that the potential of subsurface water sources is below the JAB3 path or near Point 9 microtremor with soil layers composed of sand layers with resistivity values of 0.43-4.64 ohm-meter at depth > 70 meters with $V_s$ value of 840 m/s with a Poisson’s ratio value > 0.3, the more eastward the greater the value.

1. Introduction

The landscape in Jabungan Subdistrict, Banyumanik, is included in the unit of a steep hilly structural landscape that has an average slope of 30% with a height difference of up to 275 m. The morphological conditions of this region have relatively steep conditions structurally influenced by endogenous factors such as tectonics. Based on the regional geological map of Semarang [1] in Figure 1, the formation at this location is the Kerek Formation which is consists of an alternation of claystone, marl, tuffaceous, sandstone, conglomerate, volcanic breccia, and limestone. Claystone was partly interlayered with siltstone or sandstone. Based on direct observations, it was difficult to obtain clean water that could be used for consumption. The availability water used by the majority of residents is shallow well water which is not enough good quality. There is only one deep well with a depth of 68 meters, but the water that is distributed to these houses smells unpleasant and feels slippery. One way to detect the presence of groundwater potential, which has been widely used is the geoelectric-resistivity method [2][3][4][5][6][7] or commonly known as the geoelectric method. Based on the electrical properties of the soil layer, the sensitivity of this method is very good in detecting the presence of water in the soil layer. However, this method requires two stretches of cables, each up to 250 meters in length, and it has the skin depth factor or the ability to penetrate the electric current field to depth of about one-third of the length of the electrode cable stretch [8]. The acquisition time for each point of the geoelectric method takes about 2 to 3 hours, and it takes at least 3 people to operate the resistivity meter. On the other hand, the microtremor method has relatively compact equipment, lightweight, easy operation with only 1...
person, and relatively short data acquisition. The microtremor method has a sensitivity to shear waves that cannot propagate through the fluid, so this method is quite sensitive to the presence of groundwater in the aquifer layer.

According to Yuliyanto et al. [9] one method to determine the condition and physical properties of the soil with a geophysical approach is the microtremor method which has a pretty good correlation of data to the measurement data by the geoelectric resistivity method. In this study, in addition to using the geoelectric method, in the search for aquifers in the Jabungan area microtremor method is used as a comparison method, with measurement points in line with the point trajectory of the geoelectric method. The microtremor method was used to support the analysis of the groundwater aquifer, which was carried out by the geoelectric method. The 1D profiles from the geoelectric method will be correlated with the 2D profiles from the microtremor method on the same path.

2. Geoelectric method
One way to detect the presence of groundwater potential in the presence by using the geoelectric method. In geoelectric measurements, the resistivity type of low frequency alternating electric current has flowed into the earth through the current electrode, and the resulting potential distribution is measured through the potential electrode. The electrode layout commonly used is the Schlumberger configuration and the Wenner configuration. The first configuration has advantages in terms of resolution towards the vertical, while the second configuration is very sensitive to lateral changes, so it is good for surveys in areas with many lens lithological arrangements or in fault lines [10]. Geoelectrical resistivity measurements are based on differences in resistivity values between various subsurface materials. Resistivity geoelectric utilize the electrical resistivity properties of rocks to identify subsurface structures. The principle of the type resistance geoelectric method is to inject current into the ground using a pair of current electrodes and measure the response in the form of a voltage using a pair of potential electrodes in a configuration. This method is done by measuring the potential differences caused by the injection of currents into the earth. The properties of the formation can be described by three basic parameters, namely electrical conductivity, magnetic permeability, and dielectric permittivity [11]. The conductivity of porous rocks is produced by the conductivity of the fluid that fills the pore, interconnection of the pore space, and the conductivity of the interfacial of the bolt and the pore fluid [12].

The geoelectric resistivity method consists of two current electrodes, two potential measuring electrodes, a DC current source, and a current and voltage measuring device. The variation of electrode...
configurations made possible in resistivity geoelectric surveys can be seen in Fig 2 [13]. The maximum sensitivity of the entire configuration is obtained in the area near the measuring electrode. The choice of electrode configuration in the field investigation depends on: description of the type of location (configuration sensitivity to vertical and horizontal changes in subsurface resistivity and depth of investigation), the sensitivity of the resistivity geoelectric instrument, background noise level, and signal strength.

**Figure 2.** Various electrode configurations in the resistivity method [13]

For the resistivity geoelectric method used, the Schlumberger configuration aims to identify the resistivity continuity vertically [11] as given in Figure 3, using 2 potential electrodes and 2 current electrodes. Measurements are made by injecting current through the AB electrode and potential difference measurements are made at the MN electrode. P1 P2 is the potential measured at the MN electrode and C1 C2 is the measured current at the AB electrode [12]. The results of data measurements in the field obtained the potential value and the current measured with a certain distance. From this value the resistivity value of the rock can be seen but only an apparent resistivity value. The apparent medium resistivity is calculated based on the equation [8][11][12]:

\[
\rho = K \frac{A V}{I}
\]  

(1)
where \( \rho \) is the apparent resistivity with units of \( \Omega \text{m} \) (ohmmeter), \( K \) is the geometrical factor of the electrode configuration, \( AV \) is the measured potential between the potential electrode and the unit \( V \) (volts), and \( I \) is the measured electric current between the current electrodes with unit \( A \) (amperes). Geometry factors vary depending on the type of configuration used during the data collection process in the field. Geometry factors for the Schlumberger configuration are shown by the equation [8][11][12]:

\[
K = \frac{\pi}{4} \left( \frac{(AB)^2 - (MN)^2}{MN} \right)
\]

where \( K \) is the geometry factor in the configuration, \( \pi \) is a constant (=3.14), \( AB \) is the distance of current source A to current source B (m), and \( MN \) is the distance of potential source M to potential source N (m).

3. Microtremor and Poisson ratio

Microtremor is low amplitude vibration around 0.1-1 micron and velocity amplitude of 0.0001-0.01 cm/sec at the ground surface caused by various natural factors such as wind, sea waves, vehicle noise, and others [14]. The microtremor was acquired by Omori in 1908, then developed by Kanai and Tanaka in 1961, and then in 1970 Nakamura [15] to estimate the resonant frequency and local geological amplification factors from microseismic data. From this microtremor data, one of the elastic parameters of the rock can be extracted the Poisson Ratio (\( \sigma \)), which is the ratio of transversal strains or contractions to longitudinal strains or extensions resulting from changes in normal stress due to compression or dilation. In the form of the ratio of the velocity of the longitudinal wave \( V_p \) to the shear wave \( V_s \), the Poisson’s ratio can be written as [16]:

\[
\sigma = \frac{V_p^2 - 2V_s^2}{2(V_p^2 - V_s^2)}
\]

In general, the elastic parameters of rocks largely depend on their lithological properties, one of which is water saturation. In a fluid medium that has zero rigidity, there is no shear wave that propagates, and the magnitude \( \sigma \) in the fluid is 0.5. The porous sediment liquid saturation causes an increase in P-wave velocity, which results value \( \sigma \) will increase. It is generally known that seismic wave propagation from unsaturated sediments to saturated sediments will increase the P-wave velocity and consequently, the Poisson ratio tends to increase in magnitude. At constant pressure \( \sigma \) increases with increasing water saturation and with increasing porosity.

4. Methods

This research was conducted by resistivity and microtremor geoelectric data acquisition by first conducting a geological survey to determine the appropriate measurement point. The geoelectric data obtained is then processed using IP2WIN software ver 3.0.1.a.7.01.03, while the microtremor data is processed using geopsy 3.2.2 software, and inversion is performed using dinver software in the geopsy software. Microtremor data acquisition was conducted at 9 locations and resistivity geoelectric data acquisition was conducted at 3 locations, namely JAB1 point which was coincident with microtremor Point 5, JAB2 which was coincident with microtremor Point 2, and JAB3 which was coincident with microtremor Point 9. The location of JAB1 was located in the Alluvium layer, JAB2 was located in the Kerek Formation, and JAB3 was located on the border of the Kerek Formation with alluvium. The two geoelectric location points (JAB 1 and JAB2) were both connected in one path having the same path as 6 microtremor measurement points (Points 4-5-6-2-3-1), while another geoelectric point (JAB3) was located within the 4 microtremor measurement path (Points 7-4-8-9). Microtremor Point 4 was crossed by these 2 lines. The 1D resistivity profile of each geoelectric measurement falls within the corresponding 2D shear wave velocity and the Poisson's ratio profilea. Then the 1D resistivity profiles as well as the shear wave velocity profiles and the Poisson Ratio were correlated for the analysis.
of the presence of the groundwater aquifer layer. The image of these measurement locations is given in figure 4.

**Table 1. Location of HVSR and geoelectric-resistivity surveys**

| Point | Easting | Northing | Elevation (m) | Point | Easting | Northing | Elevation (m) |
|-------|---------|----------|---------------|-------|---------|----------|---------------|
| 1     | 439226  | 9217600  | 116           | 6     | 439121  | 9217204  | 67            |
| 2/JAB2| 439180  | 9217318  | 85            | 7     | 438915  | 9217049  | 77            |
| 3     | 439185  | 9217445  | 98            | 8     | 439211  | 9217177  | 67            |
| 4     | 439091  | 9216981  | 71            | 9/JAB3| 439197  | 9216868  | 66            |
| 5/JAB1| 439111  | 9217119  | 67            |       |         |          |               |

Microtremor data was obtained using a three component seismometer. Then from the comparison of the vertical component spectrum (HVSR) to the spectra of the horizontal components, an amplification curve for the dominant frequency is obtained. Then the HVSR curve is converted to obtain the longitudinal wave velocity $V_p$ and the shear wave velocity $V_s$ (and density) with certain layer thicknesses depending on the HVSR curve obtained. Because the shear wave cannot propagate through the fluid, the speed will decrease or become smaller if it passes through a layer of soil or rock that is saturated with groundwater, or it is said $V_s$ is getting lower. Then for the Poisson Ratio value as given in equation (2) with decreasing value of $V_s$, the Poisson Ratio value will increase. From the profile $V_s$ to the depth at each measurement point then a grid of values is made for the measurement path that forms a straight line.

**Figure 4.** Location of measurement points for geoelectric and microtremor data in Jabungan Village

5. **Results and discussion**

5.1 **Geoelectric data**

Measurement data in the form of AB/2 graphs on apparent resistivity for each measurement path are given in Figure 5 to Figure 7. After refining the AB/2 curve to pseudo resistivity for each measurement trajectory then data processing is then performed then by using the IP2WIN. The rock resistivity of each
layer is given in Table 2, with the description of the material making up the layers arranged according to Table 3.

Because the constituent rocks are different, the profile of the apparent resistivity curve is also different. In Figure 5 and Figure 6, the apparent resistivity curve is getting to the right as it goes up, which can be interpreted as the deeper the layer depth has the greater the resistivity value. In Figure 7 there is a curve profile with 2 peaks on the left and right sides with a low apparent resistivity value in
the middle. Figure 5 is an apparent resistivity curve and the results of the inversion was measured in the Alluvium layer, Figure 6 is located in the Kerek Formation, while the Figure 7 was located on the border of the Kerek Formation with alluvium layer.

Table 2. Resistivity of ground layers and its lithology beneath each measurement path

| Path | Density (ohm-m) | Thickness (m) | Depth (m) | Lithology       |
|------|----------------|---------------|-----------|-----------------|
| JAB1 |                |               |           |                 |
| 1    | 0.0043         | 0.02          | 0.02      | Sandy clay      |
| 2    | 11.3           | 4.4           | 4.4       | aluvium         |
| 3    | 2.53           | 39            | 43        | Sandy clay      |
| 4    | 10             |               |           | Alluvium?       |
| JAB2 |                |               |           |                 |
| 1    | 0.0043         | 0.4           | 0.4       | Clay-sand       |
| 2    | 5.84           | 4.2           | 4.6       |                 |
| 3    | 10.8           | 92            | 96        |                 |
| 4    | 0.355          |               |           |                 |
| JAB3 |                |               |           |                 |
| 1    | 4.64           | 2.2           | 2.2       | sand            |
| 2    | 0.509          | 5             | 7.2       | ground water    |
| 3    | 11             | 34            | 41        | aluvium         |
| 4    | 0.433          | 29            | 70        | ground water    |
| 5    | 0.0212         |               |           |                 |

Table 3. Correlation of resistivity value and its lithology[11]

| Lithology     | Resistivity (ohm-meter) |
|---------------|-------------------------|
| Sand          | 1 – 1.000               |
| Clay          | 1 – 100                 |
| Ground Water  | 0.5 – 300               |
| Alluvium      | 10 – 800                |

To distinguish and determine the lithology based on resistivity data, it is not only using the data in Table 3, but is also required understanding of the field resistivity curve profile and geological information at the research location, both on the surface and the presence of outcrops.

Based on Table 2 and Table 3 above, potential groundwater aquifers are found just below the JAB3 Point trajectory at depths greater than 70 meters. In the geological map [1] This point is located on the boundary of the Kerek Formation, which is composed of claystone with other rocks such as marl, tuff sandstone, conglomerates, volcanic breccias, and limestone with alluvium, which generally consists of clay and sand reaching a thickness of 50 meters or more.

5.2 Microtremor data
The results of microtremor data processing in the form of profile V, to depth for south-north trending trails and Poisson’s ratio profiles for the corresponding trajectories are given in Figure 8 for paths of microtremor 4-5-6-2-3-1 points and Figure 7 for microtremor 7-4-8-9 points. As seen In Figure 8, microtremor Point 6 which is a measurement point near the riverbank has a low V, value which according to Keceli [17] V, values around 200-600 m/s are alluvial clay and alluvial gravel. Based on Poisson's ratio beneath Point 6 is not a groundwater aquifer location because it has a value of 0.20-0.21.
Point 2 which has the highest Poisson’s ratio on the surface layer on this track, has a relatively high $V_s$ value of around 1250 m/s in the form of limestone. Poisson’s ratio is high because surface water is blocked by a layer of clay that is alternating at this point. Identification of deep aquifer using microtremor and geoelectric methods that is at Point 5 and Point 2 did not get the results as expected.

![Figure 8](image-url)

**Figure 8.** Profile of $V_s$ for the path of the microtremor point from point 4 to point 1 that is trending south-north (top) and the Poisson ratio profile on the same path. Point 6 is a microtremor measurement point near the riverbank (below)

For the east-west trending path as given in figure 9, below the microtremor Point 8 there is the Poisson’s ratio profile which is getting greater in the east. The results of the estimation of the aquifer by the geoelectric method on this path obtained the potential of aquifers at depths greater than 70 meters below the Point 9. The shear wave velocity or $V_s$ value below this point is 550 m/s at the surface and at a depth of 70 m the $V_s$ value is 840 m/s with a Poisson’s ratio of greater than 0.24 and getting down the greater. The results of both methods show a positive correlation.

In several studies that we are currently conducting and have not yet published, including in Tembelang, Candimulyo, Magelang and in Jetak, Getasan, Semarang Regency using the solely microtremor method, the presence of aquifers can be identified in areas that have a Poisson ratio value greater than 0.3. The greater the Poisson’s ratio value, the more potential groundwater that can be identified. In Jetak area with Poisson’s ratio $> 0.4$, groundwater aquifer is obtained at a depth of about 50 meters with a discharge of 2 liters per minute.
Figure 9. The Vs profile with respect to the depth for the microtremor point path from Point 7 to Point 9 that goes west to east (top) and the Poisson ratio profile on the same path. Beneath Point 8 to Point 9 the Poisson ratio value is getting bigger.

6. Conclusion
Based on the resistivity and microtremor geoelectric measurements in Jabung Village, Banyumanik, Semarang to identify potential subsurface water sources, it can be concluded that the potential of subsurface water sources is below the JAB3 path or microtremor point 9 with soil layers composed of sand layers with resistivity values of 0.43-4.64 ohmmeter at depths > 70 meters with $V_s$ value of 840 m/s with a Poisson’s ratio value > 0.3, the more eastward, the greater the value. With the microtremor analysis based on the value of the shear wave velocity, it can be easier to identify the groundwater aquifer layer.

Acknowledgments
The authors wish to extend their gratitude to Diponegoro University for the funding allocated for this research via Riset Penelitian Pengembangan (RPP) 2020.

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