Aquifer analysis of Durensewu-Karangjati water source in Pandaan, Pasuruan using 2D resistivity method in identifying pollution of domestic waste

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Abstract. Conservation of the availability and guarantee of water quality from the spring is indispensable. One of the company as a provider of raw water in Surabaya made several efforts in maintaining the balance between quality and availability of water for sustainability. One method that can be used in aquifer monitoring of springs is the 2D Resistivity method. This study aims to describe the two-dimensional subsurface aquifers of Durensewu and Karangjati springs. The inversion result of 2D resistivity data shows the constituent rocks in the research area in the form of clay, sand, and loam clay with resistivity value 50-150 Ohm.m where sand rocks are identified as aquifer rocks at depths of 2-7 meters and a thickness of about 2-5 meters. The aquifers of Durensewu and Karangjati water sources are shown to have different systems. Escherichia coli contamination from domestic waste found in Durensewu springs is caused by aquifer connected to surface water flow, but not found in Karangjati spring.

1. Introduction

Water is the most needed need in human life. Water that exists in nature is not obtained as pure water, but rather as water containing various substances, whether dissolved or suspended. The type and quantity of the substance depending on the environmental conditions surrounding the source. Clean water is clear water, colorless, tasteless, and odorless. Natural resources such as water, can be obtained from surface water including river water, lakes, reservoirs, swamps and other puddles. Clean water is classified in the raw needs of every society living in big cities. The existence of the flowing river does not escape from the transfer function to the collection of waste that causes the river water can be polluted. Surabaya is the largest city in Indonesia after Jakarta. As one of the largest cities, the people who live are also numerous so, the availability of clean water for the community should receive special attention. Surface water resources of Surabaya City are the main watersheds of the Brantas River. But Surabaya is also supplied by subsurface springs or so-called ground water. Groundwater is moving water in the soil contained within the space between grains of soil that seep into the soil and combine to form a soil layer called the aquifer [1].

Source of spring that supplies Surabaya City there are 17 springs located in Pasuruan. The location of springs close to the settlements greatly affects water quality in the soil. This pollution can come from several factors such as the condition of lithology, geomorphology, climate and land use by the
community. In the case of land use, domestic waste from surrounding communities is discharged without regard to the ideal distance to the location of the springs so that it can lead to water pollution. Bacteria commonly contaminate this water one of them E. Coli bacteria that comes from domestic waste such as fecal disposal. To improve the quality and quantity of water in Surabaya, it is necessary to conduct a geophysical survey to determine the existence of groundwater aquifers. Also, geophysical surveys are conducted so that the exploitation does not disrupt the equilibrium between the discharge area and the recharge area. One of the geophysical methods that can be used to determine ground water aquifers is the geoelectric type resistance method. This method can describe the subsurface structure based on electrical characteristics of the type of resistance. In this research using 2D resistivity method to produce a geological model of the subsurface of Duren Sewu and Karang Jati springs. In addition, this study is intended to identify the shallow aquifer characters in both springs, as well as to determine the potential causes of E. Coli pollution so that water resources in the area can be maintained and preserved for long periods. Pollution analysis with resistivity method is marked by decreasing of resistivity value of the land because the waste is conductive, it is caused by substances contained in the waste [2]. Generally, the waste contains various types of heavy metals that are conductive. Resistivity methods can be used to determine the presence of waste and potential distribution of pollution. The indicated resistivity value has a significantly insignificant value difference, depending on the pollution medium/lithology [3].

2. Geology of Research Areas
The geography of Pasuruan District is between 1120 33 '55 "to 1130 30' 37" East Longitude and between 70 32 '34 "to 80 30' 20" South Latitude with boundaries:
   a. North: Sidoarjo and Madura Strait.
   b. South: Malang District
   c. East: Probolinggo District
   d. West: Mojokerto District

The northern part of Pasuruan District is lowland. The southwestern part is mountainous, with its peak of Mount Arjuno and Mount Welirang. The southeastern part is part of the Tengger Mountains, with the peak of Mount Bromo. Pasuruan region is surrounded by several active mountains such as Mount Semeru, Mount Welirang, and Mount Bromo. As many rivers pass through, the possibility of some areas in Pasuruan is also affected by the sedimentation of material (soil) carried by the rivers to the estuary. This sediment will gradually form a relatively wide land [4].
3. Geoelectrical Method

Geoelectric is one of the geophysical methods in the invasion of subsurface layer, the principle of this method is to drain DC (Direct Current) into the soil, the type resistant changes that occur describe the layers below the surface. Increasing the ion concentration in the fluid will increase the fluid conductivity and decrease the overall rock resistance value. There are two kinds of a geoelectric method that is Vertical sounding 1D method and geoelectric lateral mapping method. The vertical sounding (1D) geolocation method can be an alternative to drilling methods with cheaper and faster cost comparisons; using this method the depth of the material sought can be detected. The working principle of this method is to inject electric current (I) into the soil and to measure the differential electrical potential (V) response from the material below the soil surface vertically.

The basic principle of the lateral measurement of mapping is to pass an electric current from a high-voltage source device into the earth by using a current electrode at a particular measurement configuration in a measuring area, the potential difference value (mV) due to the propagation of currents in the earth medium having a compression value (Ohm) Will be obtained on the data reading.
device. In resistivity measurement, it is assumed that the earth has an isotropic homogeneous medium. But in reality, the earth is composed of different materials per layer, so that the measured resistivity value is a pseudo resistivity value that depends on the use of configurations in the measurement.

### 3.1 2D Resistivity (2D Inversion)

In practice an electric current is introduced through the C1 and C2 electrodes. While the potential difference is measured with potential electrode P1 and P2 located between C1 and C2. The arrangement of the double current electrode on the surface of the homogeneous medium is shown in figure 2.

![Figure 2](image2.png)

**Figure 2.** The potential distribution and current flow by single and double current sources on the earth’s surface [5].

![Figure 3](image3.png)

**Figure 3.** The double electrode arrangement on the surface for a homogeneous medium model [5].

Thus the potential difference in P1 due to the current injected at C1 and C2 is obtained by the following equations:

\[
V_{P_1} = \frac{i \rho}{2\pi} \left( \frac{1}{r_1} - \frac{1}{r_2} \right) 
\]

(1)

\[
V_{P_2} = \frac{i \rho}{2\pi} \left( \frac{1}{r_3} - \frac{1}{r_4} \right) 
\]

(2)

\[
\Delta V = \frac{i \rho}{2\pi} \left( \frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4} \right) 
\]

(3)

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

(4)

\[
K = 2\pi \left[ \frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4} \right] 
\]

(5)
K is a geometry factor whose magnitude depends on the distance between the electrodes used in the data processing. Figure 2 is an illustration of the current propagation by two current electrodes in a homogeneous medium with the sounding point being in the center of the current electrode. In Figure 2 above, the current flow line and the equipotential field at C1 are distorted as a result of the current propagation at C2. In a homogeneous isotropic medium, the magnitude of the potential is constant and symmetrical to the electrode. Due to the effect of current on the C2 electrode, the equipotential field formed will increasingly form not half the cylindrical sphere. If the distance between the C1 and C2 electrodes is magnified, then equipotential is less than half the cylindrical balls of the cylinder. If the medium is not homogeneous isotropy, then its resistivity is called quasi resistivity. By using a certain electrode arrangement, then the price of K (equation 6) can be known. So that the potential difference and current flow can be measured. Thus, apparent resistivity can be calculated. In the 2D resistivity measurement is usually used Wenner-Schlumberger configuration. This configuration is a combination of Wenner configuration and Schlumberger configuration. The Wenner-Schlumberger configuration has a maximum penetration of 15% better than Wenner’s configuration. The geometry factor of the Wenner-Schlumberger electrode configuration is:

\[ K = n(n + 1)\pi a \]  

Where a is the distance between the electrodes P1 and P2, and r is the ratio between C1 - P1 and P1 - P2 electrodes. The value of false resistivity is formulated:

\[ \rho = K.R \]  

### 3.2 Material Resistivity

Most minerals make unfavorable electrically conductive rocks even though some of the original metal and graphite can conduct electricity. The measured resistivity of the earth’s material is primarily determined by the movement of the mutant ions in the pores of the fluid. Here is the variation of earth material resistivity.

| Material       | Resistivity (Ωm) |
|----------------|------------------|
| Air            | ~ (tak terhingga)|
| Pirit          | 0.01 – 100       |
| Quartz         | 500 – 800.000    |
| Calcite        | 1×10^{12} - 1×10^{13} |
| Rock salt      | 30 - 1×10^{12}   |
| Granite        | 200 – 100.000    |
| Andesite       | 1.7×10^{5} - 45×10^{4} |
| Basal          | 200 – 100.000    |
| Gamping        | 5000 – 10.000    |
| Sandstone      | 200 – 8.000      |
| Slate          | 20 – 2.000       |
| Sand           | 1 – 1.000        |
| Clay           | 1 – 100          |
| Groundwater    | 0.5 – 300        |
| Sea water      | 0.2              |
| Dry pebbles    | 600 – 10.000     |
| Alluvium       | 10 – 800         |
4. Methodology
The research was conducted in two areas of the water source, namely Karang Jati and Duren Sewu, as shown in the following figure 5. The Wenner-Schlumberger configuration is used in this study. This configuration has a ratio of the distance between the C1-P1 electrodes and the space between P1-P2 at \( n \). If the distance \( P1-P2 \) is \( a \), then the distance \( C1-P1 \) is \( na \).

![Figure 4. Wenner-Schlumberger Configuration](image)

In general, the research flow can be described in the following flow diagram.

![Figure 5. 2D Measurement Design at Duren Sewu-Karang Jati Springs Source](image)
Data Acquisition
Processing and initial data analysis
Geological Survey

Water Sampling
Water Sample Test

Data Acquisition
Processing and Data Analysis
Data Analysis

**Figure 6.** Flow diagram

5. **Results And Discussion**
From secondary data in the form of Geological Map is known that the measurement area is composed of ArjunoWelirang volcanic rocks in the form of volcanic breccia, lava, breccia tuff, and tuff. While from visual observation in the field, surface lithology consists of sandstone or sand. Clays have low to medium permeability and limestone has medium permeability.

5.1 **2D Resistivity**
Figure 7. Results of the Layer Model on Resistivity Sections at Duren Sewu-KarangJati Location First and Second Trajectories

For the sand layer as an aquifer (volcanic fan area) has a resistivity value between 50-150 Ohmmeter. In the image above the sand layer is indicated in color (and ), in the color ribbon scale being 3 and 4 from the left having a resistivity value of about 93.8 Ohmmeter on the one and 100 Ohmmeter trajectories on track two. So from the 2D model, the aquifer is at a depth of 3-7 meters with a reservoir thickness of about 3-5 meters with the lithology of sand rocks as aquifers. From the above data processing results, a layer that allows play as the aquifer is given a blue highlight with a depth of 5 meters to 10 meters and a thickness of 2 to 5 meters. The coating is indicated with a resistivity value of 32 Ohmmeter to 142 Ohmmeter, which is interpreted as a sand layer. The aquifer obtained is an unconfined aquifer. The geoelectric measurements of resistance are more likely to predict subterranean lithologies as aquifers that can hold water. However, the availability of water remains influenced by the on-site hydrological systems as well as the water and drainage systems, which are also affected by the vegetation cover on the surface and weather.

5.2 Escherichia Coli Pollution

To know the contents of bacteria *Escherichia coli*, conducted laboratory tests of water samples taken at both springs. Test results are presented in table 2 and table 3 as follows.

### Table 2. Water Sample Test Result from Karangjati spring

| Parameter | Total Coli | Fecal Coli |
|-----------|------------|------------|
| Unit      | MPN/100 ml | MPN/100 ml |
| Jan       | 0          | 0          |
| Feb       | 4          | 0          |
| Mar       | 0          | 0          |
| April     | 4          | 0          |
| May       | 0          | 0          |
| Jun       | 7          | 0          |
| July      | 240        | 43         |
| August    | 9          | 9          |
| Sept      | 0          | 0          |
| Oct       | 9          | 4          |
Coliform bacteria is a type of bacteria commonly used as an indicator in the determination of the quality of food and water sanitation. Coliform is not the cause of water-borne diseases, but this type of bacteria is easy to culture and its presence can be used as an indicator of the presence of pathogenic organisms such as other bacteria, viruses or protozoa which are mostly parasites that live in the human digestive system and are contained in the feces [6].

Based on [7], Coliform bacteria is an indicator of the presence of other pathogenic bacteria. Fecal Coliform bacteria are bacteria indicator of contamination of pathogenic bacteria. Determination of fecal coliform becomes an indicator of pollution because the number of colonies must be positively correlated with the presence of pathogenic bacteria. Examples of Coliform bacteria are, Escherichia coli and Enterobacter aerogenes. So, Coliform is an indicator of water quality. The less Coliform content, that is, the better the water quality.

According to [8], Escherichia coli is a member of Coliform but not like Coliform in general. E. coli is a bacteria derived from feces and its presence effectively confirm the presence of fecal contamination in water bodies. Generally, in the feces, E. coli is 11% of Coliform. Based on the results of laboratory tests water samples showed differences in potential E. Coli bacteria contamination from both springs. Durensewu springs have higher pollution potential than Karangjati springs. It can be desensitized by the location of the Durensewu springs close to the river and also closer to the community settlements. Figure 9 shows the conditions around the spring where Durensewu springs are lower than Karangjati. This allows pollution only on Durensewu wells while at Karangjati wells are not potentially contaminated due to higher location.

| Parameter | Total Coli | FecalColi |
|-----------|------------|------------|
| Unit      | MPN/100 ml | MPN/100 ml |
| Nov       | 240        | 0          |
| Dec       | 0          | 0          |

**Tabel 3.** Water Sample Test Result from Durensewu spring

| Month | Total Coli | FecalColi |
|-------|------------|------------|
| Jan   | 240        | 18         |
| Feb   | 93         | 23         |
| Mar   | 240        | 21         |
| April | 43         | 15         |
| May   | 20         | 9          |
| Jun   | 43         | 4          |
| July  | 0          | 0          |
| Aug   | 43         | 43         |
| Sept  | 43         | 23         |
| Oct   | 93         | 21         |
| Nov   | 240        | 0          |
| Dec   | 21         | 15         |
5.3 Aquifer Characterization

The cross-section results show that the sustainability of the aquifer layer is not affected by structures such as fault which can be indicated that trapped water is difficult to pass through the underlying layer so that the manifestation of the water source that comes out to the surface. This may result from shale lithology under it or other impermeable rocks. However, further investigations are needed to determine the subsurface features with a depth of more than 30 meters.

The inversion result of the resistivity data as shown in figure 9 shows the subsurface model of the spring source area. The aquifers from the Durensewu and Karangjati springs appear to have different systems in which there is no significant signification. In other words, the two aquifers are not interconnected. Thus, E. coli bacteria found in water from Durensewu springs are not found in water from Karangjati. This is confirmed by the pattern of groundwater flow leading to the north, not to the south. This is evidenced by the flow of the river that lies between the two springs. A good water catchment area, characterized by large amounts of vegetation in the surroundings of springs, has a lithology with a high permeability character and resides in community settlement areas. This is evidenced by the superficial aquifer found around the recharge area [9]. This further proves the potential pollution of Durensewu springs where the location is close to the community settlements.
Figure 9. Layout Model Results on Resistivity Section at Duren Sewu-KarangJati Location
**Figure 10.** Cross section of the 2D resistivity cross section in Duren Sewu-Karangjati

**Figure 11.** Overlay of 2D Model Result with Real Condition of Duren Sewu-Karang Jati Springs

**Conclusion**

Based on the analysis that has been done, can be drawn some conclusions as follows. Durensewu and Karangjati springs have an aquifer with different and unrelated systems. E. Coli contamination of Durensewu water source comes from domestic pollution of the community caused by aquifer water
source Durensewu connects with a surface water flow system that has been contaminated with domestic waste surrounding environment.

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