Case study: Estimating the occurrence of sea water intrusion using geoelectrical method in Pangandaran district

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Abstract. Research to find out intrusion in Pangandaran is very interesting, because this area is close to coastal objects that has been expanding and leading tourist attraction in West Java, Indonesia. This intrusion information is useful to determine aquifer locations which indicate below that the location is saturated water. If this aquifer locations are detected in large areas and wide volume, then this location will have potential liquefaction during a big earthquake. This research could be used as the first step before the next research to measure and calculate on either location by detail grid and radius with these 2 lines, so it is gotten direct and large distribution of sea-water intrusion. The purpose of this study is to identify the subsurface structures to get an overview of sea-water intrusion. The method used is geoelectrical based on the electrical resistance value of the rock type. The results of the measurement of 2 lines and data processing showed that the line in Pesona Park Pangandaran and the line in SMPN 1 Soccer Field Pangandaran showed the presence of sea-water intrusion that very salty with a resistance value of 0.5-2.0 ohm-meter, at a depth of 19-20 meters.

1. Introduction

These the study to find out the existence of sea-water intrusion in Pangandaran become the object of this research because Pangandaran is famous as one of beach tourist destinations in West Java Indonesia [1], close to subduction zone that can cause earthquakes [2]. If a large earthquake occurs in an area of sea-water intrusion that is saturated with water in large and wide volumes, there is potential for occurring catastrophic liquefaction [3].

Pangandaran's projection as a leading tourism and expansion center [4-5] will have an impact on the Pangandaran coastal area which has a risk of faster and wider sea-water intrusion. Anthropic activity due to urbanization and the expansion of tourism influences coastal hydrologic systems [3].

Sea-water intrusion is the infiltration of sea-water into an aquifer on land or it can also be defined as the movement process of sea-water to the surface through an aquifer [6]. Aquifers must not only be permeable but must also be porous and are found to include rock types such as sandstones,
conglomerates, fractured limestone, unconsolidated sand, gravels, and fractured volcanic rocks (columnar basalts). [7]. visually the location of the aquifer is shown in Figure 1.

By finding the area that has the potential of liquefaction it can be used as a disaster mitigation step, as preparedness to anticipate that every building or settlement is not located above this area. The study was conducted at 2 (two) locations in the Pangandaran District using the geoelectrical methods by each location taking 1 (one) line so that there were 2 lines measured. The length of each line is 250 m, then two lines were processed to obtain imaging results.

The acquisition of geoelectrical measurements was carried out on 25-27 March 2019, then the processing and interpretation were carried out at the BMKG Research and Development Center in Jakarta.

Figure 1. Visualization of sea-water Intrusion

Figure 2. Geoelectrical measurement location

2 (two) measurement points were located in the Pangandaran area and SMP 1 Pangandaran shown in Figure 2. Two measurement points in Figure 2 are in the coordinates shown in Table 1.

| No | Lat         | Lon         | Location                      |
|----|-------------|-------------|-------------------------------|
| 1  | -7.684871   | 108.650519  | Pesona Park Pangandaran       |
| 2  | -7.683739   | 108.648137  | SMPN 1 soccer field Pangandaran |

The main purpose of this study was to delineate the sea-water intrusion in a coastal aquifer in Pangandaran.

2. Methods
In this research, the methods that can be used to find out the existence of sea-water intrusion is the geoelectrical methods. Geoelectrical methods are used extensively in groundwater mapping for investigation aquifer vulnerability. The geoelectrical methods are capable of mapping low and high resistive formations. Therefore, this method is a valuable tool for vulnerability studies [8-10].

Geoelectrical is one of the geophysical methods used to study subsurface conditions by utilizing the electrical properties of rocks. Each rock has different properties in the flow of electric current, this is caused by several factors including porosity, the resistivity of fluids in pores, mineral content, degree of
water saturation, and so on. Therefore, the geoelectrical methods can be used to estimate subsurface geological conditions based on the resistivity distribution which correlates with rock porosity [11,12].

The basic principle of the geoelectrical methods is to inject current into the earth and then measure the electrical potential arising from current input into the ground. The purpose of this method is to achieve information on the resistivity structure so that the obtained value of rock formations. In a homogeneous ground (halfspace) the current flow radially out from the current source and the arising equipotential surfaces run perpendicular to the current flow lines and form half-spheres (Figure. 3a).

In the common situation with both a current source and a current sink the current flow lines and the equipotential surfaces become more complex (Figure. 3b). In reality, the current flow lines and the equipotential lines will form an even more complex pattern as the current flow lines will bend at boundaries, where the resistivities change [8].

![Figure 3. Simplified current flow lines and equipotential surfaces arising from (a) a single current source and from (b) a set of current electrodes (a current source and sink) [8].](image)

From the measured electrical potential value, apparent resistivity will be obtained. This electrical potential value depends on the electrical properties of the rock from the medium transfer and the configuration of the electrodes. In general, apparent resistivity values are formulated by the equation [8]:

\[ \rho_a = K \frac{\Delta V}{I} \] (1)

In equation (1) \( \rho_a \) is apparent resistivity, \( \Delta V \) is the measured potential, \( I \) is transmitted current, and \( K \) is the geometrical factors of the electrode configuration. \( K \) value depends on the configuration of the electrode array. Each configuration has a different \( K \) formulation. In this study using three configurations, namely: Wenner, Dipole-Dipole, and Schlumberger.

Using the theory of the assumption that the earth is homogeneous isotropy, configuration changes will not affect the measured resistivity (the resistivity will be constant). The earth is not homogeneous so changing the electrode distance measurement will give different measurement results. Electrode configurations that are set with the distance between the electrodes are known to make it easier to detect visible resistivity values. Significant variations in resistivity values as a function of the electrode
distance qualitatively describe variations in intermediate resistivity as a function of depth. Medium resistivity variation is obtained quantitatively through modeling [13].

From the apparent resistivity value which is then processed using IPI2win software, these results can then be analyzed lithologically and used as input to RockWorks to obtain images with color images of each layer of different types.

From the results of IPI2win processing, the upper and lower limits are taken from the rock layer. The layer type is then incorporated into the track coordinates that have been measured using GPS, so that later after processing using Rockworks analysis it will be seen that the subsurface layers differ in color according to the layer type.

In the case of an intrusion search, a preliminary study can be carried out by determining the interpretation of rock layers containing the degree of saturation of water types in various layers of sediment and their reactivity values. In this method, each rock layer is represented by variations in the resistivity values shown in Table 2 [14].

| Resistivity (Ohm.m) | Sediment                                      | explanation                                      |
|---------------------|------------------------------------------------|--------------------------------------------------|
| 0.5 - 2             | soil with little sand                         | saline water zone very salty                     |
|                     | (granules) or consolidated clay                |                                                  |
| 2.0 - 4.5           | sand (granules) or consolidated clay           | saline water zone                                |
| 4.5 - 10            | sandy-clay                                     | brackish water is little salty                   |
| 10 - 15             | sand, gravel-clay                              | brackish water                                   |
| 15 - 30             | sand, gravel little clay                       | groundwater low quality                          |
| 30 - 70             | sand, gravel very little clay                  | groundwater middle quality                       |
| 70 - 100            | sand, gravel no clay                           | groundwater high quality                         |
| > 100               | rough sands, gravel no clay                    | groundwater very high quality                    |

The resistivity values of each rock layer are determined by the type of constituent material, the water content in the rock, and the porosity of the rock. In this study, from the 3 (three) geoelectrical methods configurations, the Dipole-dipole, Schlumberger, and Wenner configurations are expected to validate the respective measurement data, regarding the presence or absence of intrusion in path measurement. 7 (Taman Pesona) and path 12 (SMPN 1). Lithology will also be used as a rock type study under the research area Type of Geoelectrical Methods Configuration [15].

There are 3 types of configurations performed in this study, namely:

2.1 Wenner configuration

The Wenner configuration is a configuration in which the distance between the electrode and the electric current has the same value. \( r_{AC} = r_{CD} = r_{DB} = a \). When there are electrodes or currents will move, they move together. It has a strong signal and the accuracy of the voltage reading on the MN potential is very good because the CD electrode remains relatively close to the AB electrode. The Wenner configuration image is shown in Figure 4 as follows:
This configuration has a geometry factor value:

\[ K = 2\pi a \]  

(2)

2.2. Schlumberger configuration

Schlumberger configuration is a configuration in which the distance between the electrode and the electric current is not the same value.

The ideal principle of Schlumberger configuration is that the distance of the CD is made as small as possible, so the voltage reading the CD distance gets smaller when the AB distance is relatively far. Requires current-sending equipment that has a very high DC power voltage to overcome a small MN voltage reading. The advantage of the Schlumberger configuration can detect the non-homogeneity of rock layers on the surface (by comparing the apparent resistivity values when there is a change in the CD distance. An overview of the Schlumberger configuration is shown in Figure 5 as follows:

\[ K = \frac{n(L^2-a^2)}{4a} \]  

(3)

2.3. Dipole-Dipole (Double Dipole) configuration

Dipole-Dipole or Double Dipole Configuration is a configuration where the distance between electrode A and electrode B is equal to the distance between electrode C and electrode D. The current electrode and the potential electrode are in the distance \((n \times a)\), where \(n\) is an integer. Variation \(n\) is used to get a certain depth range, the greater the \(n\) then the depth obtained is also greater. In this study the \(L\) value is used, namely, the value of \((n \times a) + 2(1/2 a)\), each half of the AB and MN current electrodes, so that \(L = (n \times a) + a\). This configuration schema is shown in Figure 6 and Figure 7.
In mathematical equations, the value of the geometry factor (K) for the dipole-dipole configuration is as follows:

\[ K = \pi an (n + 1)(n + 2) \] (4)

\[ K = \frac{nL(L^2-a^2)}{a^2} \] (5)

Visually, the resume of difference in sensitivity and resolution of each configuration is shown in Figure 8 as follows [16]:

3. Results and conclusions
The contours of the resistivity cross-sections measured at each cross-section are shown in Figures 9 to Figures 11 for line 7 and Figure 12 to Figures 14 for line 12.
3.1. Line 7 on pesona garden

The results of line 7 (Figure 9) using dipole-dipole configuration show that blue degradation shows a resistance range of 0.7-1.52 then in the range of 1.52-2.92 to either color degradation. This resistance value in blue degradation shows compatibility with previous research tables, which indicate the presence of very salty seawater intrusion in the depth range of 16.2-23.5 m.

The results of line 7 (Figure 10) using the Schlumberger configuration show that the degradation in blue shows the value of the resistance range 0.7-1.52 then in the range of 1.52-2.92 to either color degradation. The resistance value in this blue degradation indicates compatibility with the previous research table, which indicates the presence of very salty seawater intrusion in the depth range of 14.8-28.8 m.

Color degradation using the Schlumberger method on line 7 looks asymmetrical, even though it is in the same depth range. This might occur because of the characteristics of CD current data retrieval which can indicate the existence of non-homogeneity.

The results of line 7 (Figure 11) using the Wenner configuration show that blue degradation shows a resistance range of 0.7-1.52 then in the range of 1.52-2.92 to either color degradation. The value of resistance in blue degradation shows that it is by the previous research table, which shows the presence of very salty seawater intrusion in the depth range of 14.8-23.7 m.

![Figure 9](image9.png)

**Figure 9.** The contours of the cross-section of resistivity line 7 in the Pesona garden are measured by the dipole-dipole method.

![Figure 10](image10.png)

**Figure 10.** The contours of the cross-section of resistivity line 7 in the Pesona garden are measured by the Schlumberger method.
3.2. Line 12 on the SMPN 1 soccer field
The results of line 12 (Figure 12) using the dipole-dipole configuration show that blue degradation shows a resistance range of 0.7-1.52 then in the range of 1.52-2.92 to either color degradation. This resistance value in blue degradation shows compatibility with previous research tables, which indicate the presence of very salty seawater intrusion in the depth range of 10.1-23.5 m. The results of line 12 (Figure 13) using the Schlumberger configuration seen blue degradation shows the value of the resistance range 0.7-1.52 then in the range of 1.52-2.92 to either color degradation. This resistance value in blue degradation shows compatibility with previous research tables, which indicate the presence of very salty seawater intrusion in the depth range of 14.8-28.8 m. Similar to line 7, color degradation using the Schlumberger method is also seen in line 12 also looks asymmetrical with a range at the same depth. This proves that the use of Schlumberger configurations can show non-homogeneity.

The results of line 12 (Figure 14) using the Wenner Configuration show that degradation in blue indicates a resistance range of 0.7-1.52 then in the range of 1.52-2.92 to either color degradation. This resistance value in blue degradation shows compatibility with previous research tables, which indicate the presence of very salty seawater intrusion in the depth range of 14.8-28.8 m.
Figure 13. The contours of the cross-section of resistivity line 12 in the SMPN 1 soccer field are measured by the Schlumberger method.

Figure 14. The contours of the cross-section of resistivity line 12 in the SMPN 1 soccer field are measured by the Wenner method.

The results of the study show that of the three configurations, the dark blue color indicates the resistivity value in the range of 0.5 - 2.0 ohm-meter, so line 7 indicates that seawater intrusion has entered as an aquifer at a depth of 14.8 - 28.8 m, and for line 12, which is indicated as a sea-water intrusion at a depth of 13.0 - 28.8 m. This result indicates that from line 7 to line 12 more shallow. It is needed next research to find distribution sea-water intrusion so that is known wide and large intrusion.

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Author contributions
Conceived and designed the manuscript: TK. Collected the data: TK, RSY, BS, TH, AAM. Processed the data: BS. Analyzed the data: TK. Contributed reagents / materials / analysis tools: TK, RSY, BS, TH, AAM. Wrote and revised the manuscript: TK, RSY. Submitted the manuscript: RSY. All authors have read and approved the manuscript.