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Identification of seawater intrusion using geoelectrical resistivity method in the Goa Cina Beach Malang Area, Indonesia

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Abstract. Seawater intrusion can cause groundwater that is looked fresh initially but becomes brackish and even salty. It makes decreasing the quality of groundwater in the area. The Goa Cina Beach, Malang has a geological structure of rock in limestone, sand, and gravel. These rocks have greater porosity, so that the potential to pass water or water infiltration is also quite large, both freshwater and saltwater. Starting from these problems, it is needed to identify groundwater distribution that is not affected by the seawater intrusion process. The geoelectric method effectively determines geological parameters such as depth of bedrock, minerals, fluids, and shallow exploration to identify groundwater aquifers. Data acquisition was carried out using the geoelectrical resistivity method with Wenner configuration with three measurement points. Furthermore, the data processing used Res2dinv Software. The results showed that the measured resistivity value between 0.01000-501 Ωm with a maximum depth of 19.9 meters. The seawater intrusion distribution is assumed to be on lines 1 and 2 at an average depth of 10-19.9 meters with a resistivity value of 0.01000-0.230 Ωm. At the same time, the area that is not expected to experience seawater intrusion is on Line 3. The making of wells for coastal areas needs to consider the distance from the shoreline and rock porosity for minimizing the potential for seawater intrusion.

1. Introduction

Seawater intrusion is the process of entering or infiltration of seawater into the pores of rocks and contaminating groundwater that contains it. So the groundwater that was originally fresh becomes brackish and even saline. This caused reduces groundwater quality within the area. Seawater intrusion is a global problem that affects water quality, vegetation, and soil conditions along the coastline [1,2]. Freshwater damage can threaten the sustainability of freshwater supply and economic growth for coastal communities [3-5].

Seawater intrusion is a serious problem for the community [6]. The main problem is in the form of health, where the groundwater conditions contaminated by seawater intrusion can be identified through the amount contained in Chloride (Cl) ions [7]. This is caused the Natrium Chloride (NaCl) contained in seawater is formed of 39.3% Natrium (Na) and 60.7% Chloride (Cl), so the value of Cl is sufficient to describe the magnitude of the influence of seawater intrusion in groundwater [7].

In the southern Malang Regency, there are many settlements around the coast and most likely the settlement will experience a process of seawater intrusion. The geological conditions of the Malang Regency in the south are generally composed of karst, sand, and gravel rocks [8]. Karst, sand, and

gravel including rocks that are easy to escape water because it has a fairly large porosity of the rock. Goa Cina Beach is one of the beaches in the Malang Regency, most of the rocks in the area are hollow limestone which causes seawater to easily enter the groundwater layer, so that the groundwater in the area becomes salty. Therefore we need a method that can be used to investigate the distribution of seawater intrusion [9].

Several geophysical methods can be used to detect the subsurface layers, including the presence of groundwater [10]. The subsurface investigation methods commonly used in exploration are: geological methods, gravity methods, magnetic methods, seismic methods, and geoelectric methods. Of the several methods, the most commonly used method is the geoelectric method with good results and is environmentally friendly [11-13].

The geoelectrical resistivity method can detect the inhomogeneous of the rock layers on the underground surface by comparing the apparent resistivity values when the electrode distance changes. That resistivity value is used to determine the condition of the rock or mineral [14]. The geoelectrical resistivity method is one of the effective methods used for determining geological parameters such as depth of bedrock, minerals, fluids, and near surface exploration such as identification of groundwater aquifers [9,15].

From these problems, it is necessary to identify the distribution of groundwater that is not affected by the seawater intrusion process. The identification was carried out using the geoelectrical resistivity method with the Wenner configuration. The Wenner configuration is used in this study because it is superior in data acquisition by sounding-mapping and easier in the process of data acquisition because the distance between the electrodes is the same.

This research is expected to provide information for the surrounding community and particularly the local village government. The information regarding the distribution of groundwater that is intrused by seawater and groundwater that is not intrused by seawater based on resistivity values in the Goa Cina Beach area of Malang.

2. Methods

Geoelectrical Resistivity Method is one of the geophysical methods that aim to determine the resistivity changes of the subsurface rock layers by flowing high voltage DC (Direct Current) into the ground through two current electrodes [9,16]. The purpose of using the geoelectrical resistivity method is to determine the value of electricity of the rocks below the ground surface. The measurement process of the geoelectrical resistivity method contains various types of electrode displacement configurations based on the electrode position. Some of the commonly used configurations are the Wenner, Schlumberger, Pole-Pole, and dipole-dipole configurations.

2.1. Wenner Configuration

The working principle of the Wenner configuration on the acquisition of geoelectrical resistivity is shown in Figure 1. Based on the Wenner configuration image uses 2 current electrodes (AB) as of current transmitters and 2 potential electrodes (MN) as receivers of the generated voltage [13]. The distance between the electrodes (a) is made the same on all electrodes in the order A, M, N, and B. Transfer of all electrodes along (na) meters, and so on until electrode N arrives at the end of the path.

The measurement results are not actual resistivity values, but it consists of various rock resistivity values, because of the vertical and lateral variations, which are directed as rock resistivity. The value of the Wenner configuration geometry factor (K) is shown by the following equation [17]:
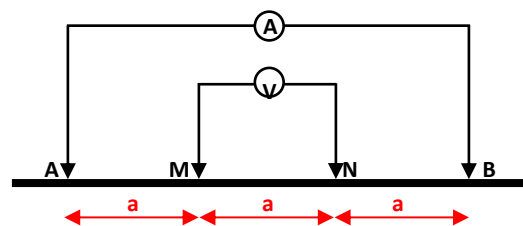
$$K=2\pi a \tag{1}$$

Figure 1. The Position Electrode of Wenner Configuration.

The Geometry Factor is substituted into equation (2) where the value of the potential difference (ΔV) and the current (I) to obtain the apparent resistivity (ρa).

$$\rho_a = K \frac{\Delta V}{I} \tag{2}$$

2.2. Data Acquisition

Some supporting data must be prepared before data acquisition as initial information, such as regional geological maps and conditions in the field. The data obtained include current and potential electrode distance, current (I), potential difference (V), and geometric factor (K).

Data acquisition was carried out around the Goa Cina Beach, Malang, with a distance of 50 to 300 meters from the sea. The measurements were made using a Wenner configuration on three lines with a length of line 1 and 3 is 150 m, line 2 is 250 m, and a distance between the electrodes is 10 m. The detailed research design is shown in Figure 2 below:
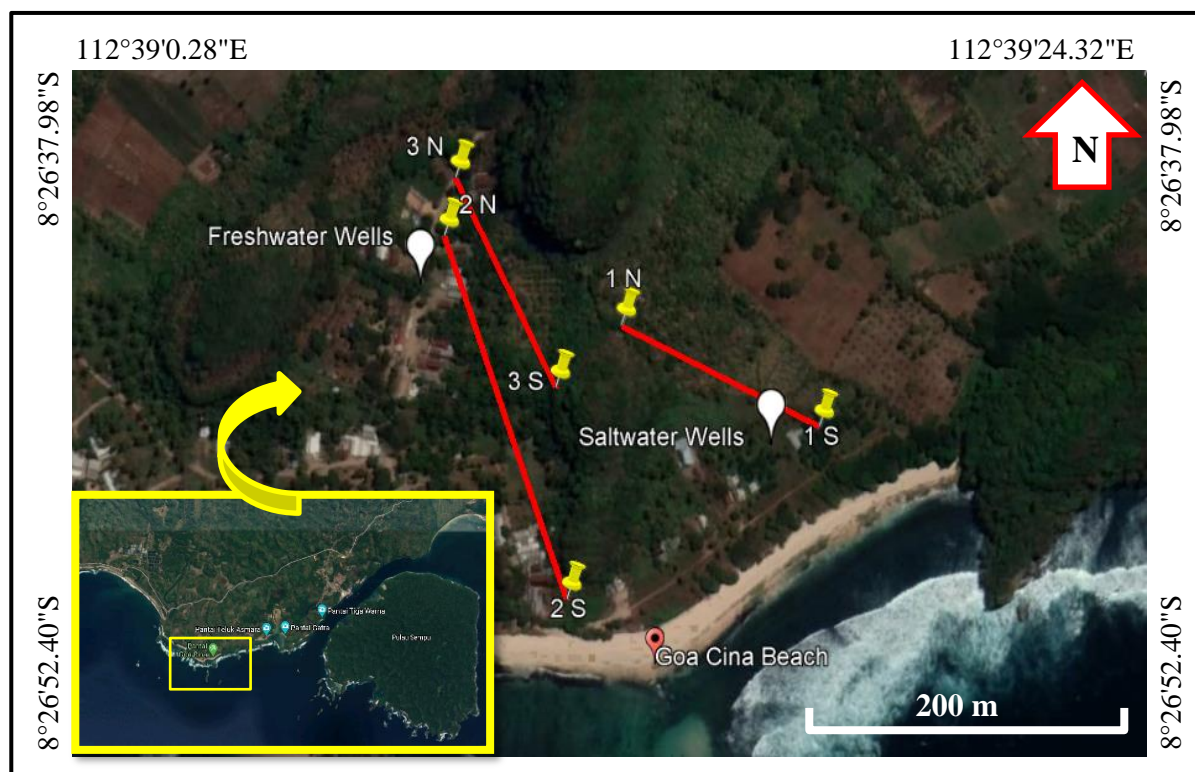

Figure 2. Research Survey Design

2.3. Data Processing

The data obtained from the field is raw data and then entered into Microsoft Excel to calculate the apparent resistivity (ρ) with geometry factor (K). Then performed the inversion process for least squares, namely the approach method for the formation of equations from points (regression). This inversion process aims to convert the apparent resistivity value into a resistivity value that is close to the actual state.

Data processing was carried out using Res2Dinv software and a 2D cross-section that depicts the distribution of rock resistivity on the underground surface will be obtained [18]. The 2D cross-section consists of the length of the line, the resistivity value, and the depth variation. The interpretation process needs to be supported by additional data such as the distribution of rock resistivity values and geological data in the study area [19].

3. Result and Discussion

Based on the geological map of the turen sheet [8] the study area is included in the Swamp and River Deposits formations which are composed of gravel, sand, clay, and plant remains. The rock layer composed of gravel and sand has a greater porosity, so the potential to pass water or water infiltration is also large both freshwater and saltwater.
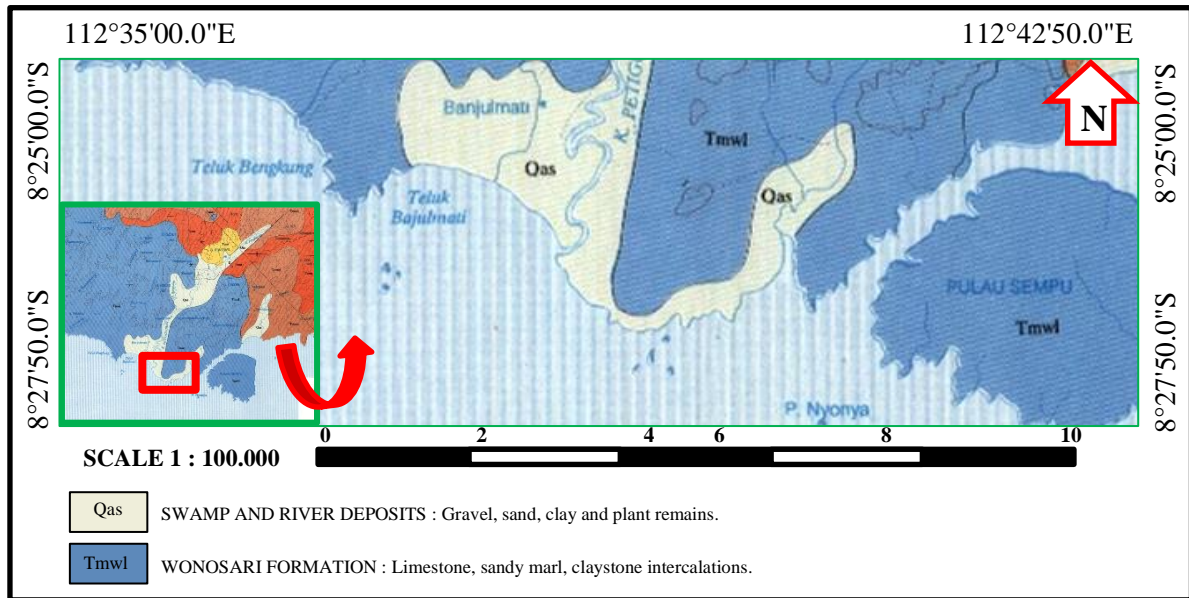

Figure 3. Turen Geological Map Sheet [8]

The water infiltration area can be determined by observing the subsurface aquifers. Aquifers are underground layers that contain water and can be passed by water [20]. Based on Halliday et al, [21] The resistivity value for groundwater is in the range of 1-300 Ωm, while the resistivity value for saltwater is slightly lower at around 0.2 Ωm.

Figure 4 is the result of 2D interpretation obtained from three measurement points in the area around the freshwater wells and saltwater wells. It is according to the survey design in Figure 2.
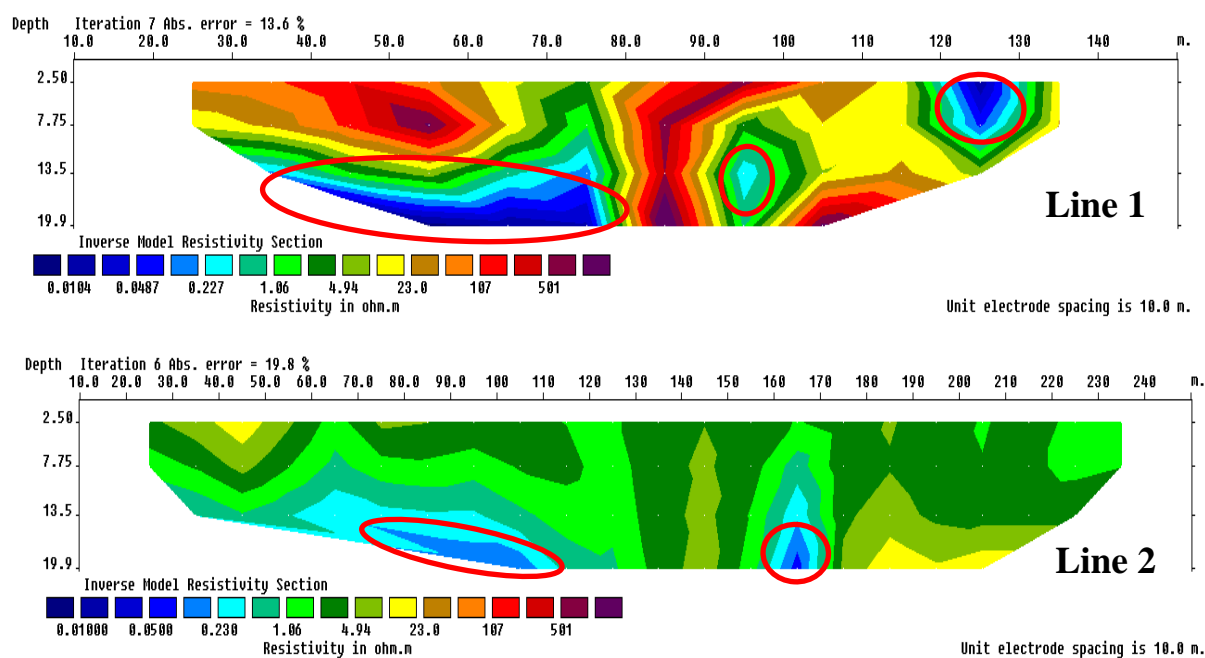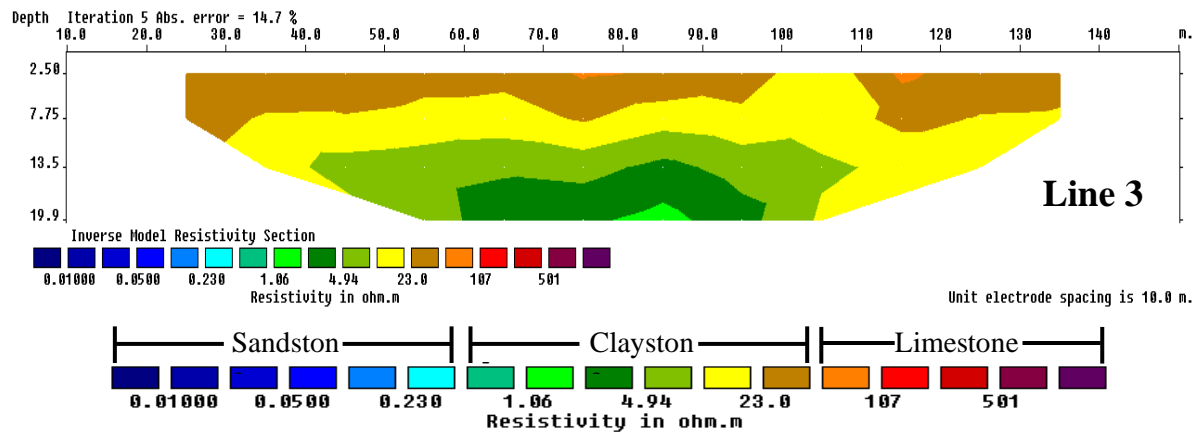
Figure 4. 2D Interpretation on Line 1, Line 2, and Line 3

Figure 4 is the result of a 2D cross-section interpretation of each line using the Wenner configuration. The three 2D sections are interpreted qualitatively from field information and geological maps. Based on Figure 4, the measured maximum depth is 19.9 meters from the surface. In this measurement, the resistivity value is obtained between 0.01000-501 Ωm.

Based on research conducted by Sunaryo et al [9] on the identification of seawater intrusion at The Amal Beach Tarakan, Indonesia in 2018, the resistivity value of rocks in seawater intrusion areas is less than 1.5 Ωm with a depth of approximately 10 meters from the surface. Based on the geological map of the Tarakan and Sebatik sheets, the Amal area, Tarakan has a geological structure of alluvium which is composed of mud, silt, sand, pebble and cobble, it is coastal, river, and swamp deposits. Similar research was conducted by Muhni et al [22] about the susceptibility of seawater intrusion at Banda Aceh City, Indonesia in 2018. The research shows, that the resistivity value of seawater intrusion in the research area is below 1.45 Ωm with a depth varies from 0 to 34,1 meters. While based on the geological map of Banda Aceh sheets, the Banda Aceh area contains alluvium with sediment deposits consisting of mud, sand, and gravel.

Figure 4, the area that is suspected of experiencing seawater intrusion is Line 1 at a depth of 10.0-19.9 meters stretching from 30 to 80, at a depth of 13.5 meters stretching from 90 to 100, and at a depth of 0-8 meters stretching from 120 to 130 with a value of resistivity 0.01000-0.230 Ωm. Based on field information, the saltwater well is around Line 1 with a stretch of 50-60 meters, with a distance of about 10 meters. As the saltwater well is 75 meters from the shoreline. This short distance causes seawater to seep through the porosity of the rock, causing the well intrused by seawater.

In Line 2, the area that is suspected of experiencing seawater intrusion is in the range of 40 to 110 and 160 to 170 with a depth of 10 to 19.9 meters from the surface with a resistivity value of 0.01000-0.230 Ωm. While in Figure 4. Line 3 is not found any areas intrused by seawater with an indication of low resistivity values indicated by dark blue to light blue. The area that is suspected of experiencing seawater intrusion is likely a sandstone that has a large enough porosity to easily absorb water.

The survey design in Figure 2 shows the position of the freshwater well at the northern end of line 1 and line 3 with a distance of about 275 meters from the shoreline. Whereas the saltwater well is located around line 2 with a distance of about 75 meters from the shoreline. This means that the farther of distance from the well to the shoreline, the less potential for seawater intrusion. This is caused by seawater seeping through the rocks is decreasing, or the porosity in the area is getting smaller.

The Porosity of rock is the main factor influencing the process of water escape in the soil layer. The greater porosity of the rock, so the greater the potential to pass water. As for the minimum distance in making wells in the coastal area, further research is needed to identify rocks that have the smallest porosity.

Figure 5. is a combination of a 2D cross-section with google map. Based on Figure 4, the lines that tend to experience seawater intrusion are lines that are distance close to the shoreline that is about 75 meters.
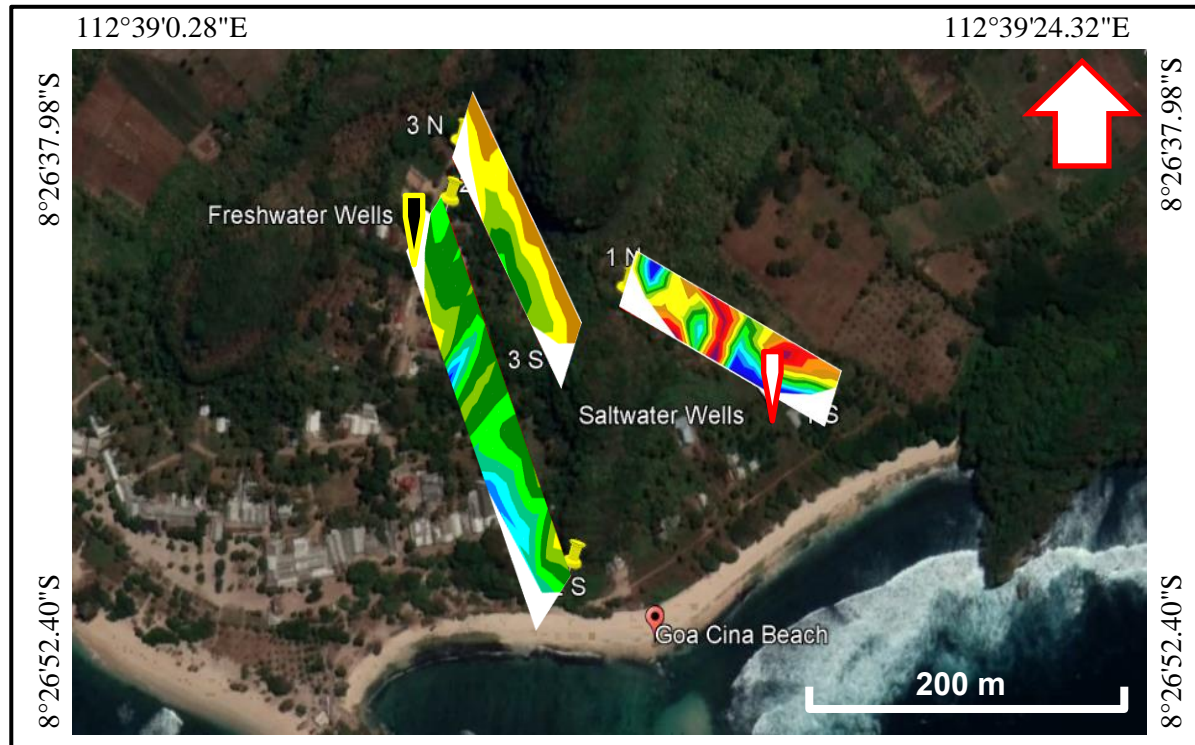

Figure 5. 2D cross-section overlay and survey design on google earth.

4. Conclusion
Beach Malang obtained a resistivity value between 0.01000-501 Ωm, with a maximum depth of 19.9 meters. The seawater intrusion distribution is suspected to be on lines 1 and 2 with a low resistivity value of 0.01000-0.230 Ωm with an average depth of 10-19.9 meters. The area suspected of experiencing seawater intrusion is likely a sandstone with a large enough porosity to absorb water easily. The porosity of a rock is the main factor influencing water escape in the soil layer. The greater porosity of the rock, so the greater the potential to pass water. As for the minimum distance in making wells in the coastal area, further research is needed to identify rocks with the smallest porosity. At the same time, the area suspected of not experiencing seawater intrusion is on line 3.

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