Sea Water Intrusion Monitoring on the Sendangbiru of the Southern Malang Coastal Area based on Geoelectrical Resistivity Data

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Abstract

The study was conducted with the objective to distinguish the presence of seawater intrusion layer or salt-water aquifer distribution along the data acquisition line at the locations. Data acquisition was conducted by using the Wenner-Schumberger configuration of geoelectrical resistivity. From this research, 4 lines and 4 points of vertical electrical sounding (VES) data for every line were obtained with the distance between electrode a as 10m.

Based on the data processing, obtained depth up to 120m with the smallest resistivity value is 0.02Ωm and the largest is 6764.52Ωm. To make the distribution of resistivity values along the path line of the study, cross sections were made until a depth of 120m. Based on the cross-section, the low resistivity value (less than 1.5 Ωm) that interpreted as a seawater intrusion layer or salt water aquifer distribution is located at varying depths. There are intrusions for the SB1 cross section, there is an intrusion at a depth of 6m-7m as far as 10m, at a depth of 6m-8m as far as 10m for the SB2 cross section and at a depth of 22m - 26m as far as 25m for the SB3 cross section.

Keywords: Sea water intrusion, Geoelectrical resistivity, Sendangbiru, Southern Malang coastal area.

Introduction

Seawater has a greater density than groundwater which is fresh water, as a result seawater will easily intruse groundwater. Naturally seawater cannot enter deep into land because groundwater has piezometric pressure stronger than seawater, so an interface is formed as the boundary between groundwater and seawater. It is a state of equilibrium between seawater and groundwater.

The influx of seawater into the groundwater aquifer system is through two processes namely seawater intrusion and upconning. Seawater intrusion in coastal areas is a process of infiltrating saltwater from the sea into fresh groundwater on land. The meeting zone between saltwater and freshwater is called an interface. In natural conditions, groundwater will flow continuously into the sea. The density of saltwater is slightly greater than the weight of freshwater types, so seawater will push fresh water in the ground more upstream. But because the high piezometric pressure of groundwater is higher than the sea level, the urge can be neutralized and the flow of water that occurs is from the marine land, so there is a balance between seawater and groundwater and there is no intrusion of seawater. Seawater intrusion occurs when balance is disturbed.

Activities that cause seawater intrusion include excessive human activity or pumping, constituent rock factors, coastal characteristics and groundwater fluctuations in coastal areas. Human activity on land and water resources without considering the sustainability of nature can have many environmental impacts. A form of human activity that impacts water resources, especially seawater intrusion, is excessive pumping well and its presence close to the coast. Aquifer-building rocks in one place are different from others, when the constituent rocks in the form of sand will cause seawater to enter more easily the groundwater. This condition is offset by the ease of seawater intrusion control with many methods. The difficult nature of releasing water is clay so that the intrusion of seawater that has occurred will be difficult to control. Rocky beaches have pores between larger and varied rocks that make it easier for seawater to enter the groundwater.

The sandy beach has a more porous texture of sand. Coral/mangrove beaches will be difficult to experience seawater intrusion because mangroves can reduce seawater intrusion. The coastal area has a function as a life support system. Coastal areas as water cycle control areas and seawater intrusion processes, have vegetation whose existence will maintain the availability of surface water reserves that are able to inhibit the intrusion of seawater towards the mainland.

The density of the type of vegetation on the border of the beach can control the movement of sand material due to the movement of currents each season. The density of this type of vegetation can inhibit speed and break down the pressure of the wind leading to the settlement. If groundwater fluctuations are high, then the likelihood of seawater intrusion is easier to occur in reduced groundwater conditions. Cavities formed by low groundwater will make it easier for seawater to suppress groundwater and fill groundwater basins/cavities. If the fluctuations remain, then it will naturally form an interface.

Seawater intrusion is a form of degradation of water resources, especially by human activity in coastal areas. This needs to be considered so that all forms of human activity in the area need to be restricted and controlled as a form of concern for the environment. The longer intrusion process can be performed taking excessive amounts of groundwater. If the intrusion has entered the well, then the well will become salty, so that it can no longer be used for daily purposes.

According to the concept of Ghyben – Herzberg, saltwater is found at a depth of 40 times the height of the groundwater level above sea level. This phenomenon is caused by the difference in the weight of the type between seawater (1,025 g/cm^3) and the weight of the freshwater type (1,000 g/cm^3)[14].

$$z = \frac{\rho_f}{\rho_s - \rho_f} h_f \qquad (1)$$

where $z = 40h_f$,

h_f = elevation of groundwater level above sea level (m), z = interface depth under sea level (m), ρs = density of seawater (g/cm^3) and ρf= density of freshwater (g/cm^3).

Upconning is the process of increasing the interface locally due to pumping in wells located slightly above the interface. When pumping starts, the interface is in a horizontal state. The longer interface rises until it reaches the well. If pumping is stopped before the interface reaches the well, the seawater will likely to remain in that position rather than return to its original state.

Seawater intrusion will result in the value of freshwater resistance decreased. The change in electricity value will be the main parameter in this study. In this case, the method of electrical geophysics will be used, i.e. the method of geoelectrical resistivity. The geoelectric method detects sub-surface conditions based on the contrast of electrical properties of earth-building rocks[15]. The geoelectrical resistivity method assumes that if the surface of the earth is injected by an electric current, the earth as a delivery that has obstacles will give rise to a certain potential different response. Ground level resistivity is related to the variety of geological parameters such as rocks, minerals and fluids. It contains, porosity and saturation of water in rocks. Resistivity electricity survey has been widely used in hydrogeology to detect the presence of water layers or aquifers, mining or mineral investigations and geoengineering in order to know sub-surface structures. Even now it is also used for environmental survey to detect environmental pollution.[1,9]

The length of the southern Malang coastal area is about 70km. In this study, a case study for the coastal areas of malang south in central location, namely the beaches of Sendangbiru. Administratively, Sendangniru beach are located in Tambakrejo village, sumbermanjingwetan district and malang district of East Java province of Indonesia. Southern Malang is a coastal area that is undergoing very rapid development. The southern Malang area is currently under construction of the southern ring road. In addition to the existence of the southern ring road, in the area there is also more development of coastal tourism and changes in land function.

The change in land function that was originally in the form of vegetation, serves as a recharge area with rooting as a retainer of intrusion into open land, residential and civilian buildings supporting tourism having an impact on the aquifer system. This research is necessary to obtain supporting data in freshwater conservation efforts by zoning the distribution of seawater intrusion conditions over time. Physiographically, the research site of the southern Malang coastline is located in the western and central southern mountains zone[4].

While geologically, as can be seen in figure 1, the research site is dominated by Wonosari formations (Tmwl) consisting of limestone, sandy marl and claystone intercalation. Another formation at this location is the Campurdarat formation (Tmcl) consisting of crystalline limestone and claystone intercalation, Mandalika formation (Tomm) consisting of andesitic basaltic lava, phorphiry latite, rhyolite and dacite, tuff member of Mandalika formation (Tomt) consisting of andhesitic rhyolitic dacitic tuffs, pumiceous tuff breccia and swamp and river deposits (Qas) consisting of gravel, sand, clay and plant remains. [7,10]

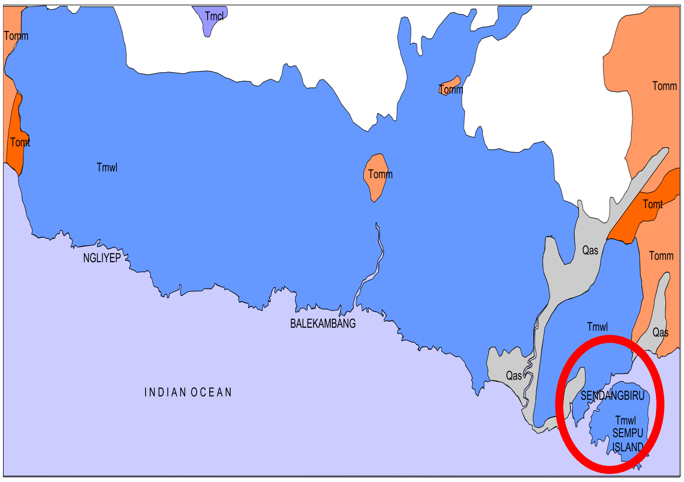

Figure 1: Geological map of Ngliyep and Sendangbiru beaches.[7,10]

Material and Methods

In this study, the Wenner-Schlumberger/ modified Schlumberger configuration with potential fixed electrodes and walking current electrodes to obtain variations in vertical electrical sounding (VES) is in use. Ves configuration is a configuration used in geoelectric resistivity methods for 1-dimensional targets. However, by using interpolation between VES points, this configuration can display both 2-dimensional and 3-dimensional targets. In this study, variations in lateral direction (cross section or 2 dimensions) were done by connecting measuring points through the interpolation process.

The use of the Wenner-Schlumberger configuration is the most appropriate option for Vertical Electrical Sounding (VES) targets on the grounds of field effectiveness and optimal accumulation error reduction. This configuration is a modification of schlumberger configuration which refers to the Indonesian National Standard (SNI) for groundwater exploration methods, namely SNI 03-2818-1992 Wenner configuration.

The resistivity method is one of the active methods in geophysics, therefore the measurement of the earth's resistivity is carried out by injecting the current into the earth through 2 current electrodes (C1 and C2) and measuring the yield of the earth's response to the injection current in the form of potential differences and resistances it inflicts on 2 potential electrodes (P1 and P2). From current value (I), potential difference (ΔV) and resistance (R) data, apparent resistivity value (ρa) can be calculated as in equation.[1,11,15]

$$\rho = k\frac{\Delta V}{I} \qquad (2)$$

where $\boldsymbol{k = 2\pi\left\{\left(\frac{1}{r1}-\frac{1}{r2}\right)-\left(\frac{1}{r3}-\frac{1}{r4}\right)\right\}^{-1}\frac{\Delta V}{I}}$

k is a geometry factor that depends on the configuration settings of the 4 electrodes that have been mentioned before.[13]

The calculated resistivity value is not an actual sub-surface resistivity value, but is an apparent resistivity value that is the result of the contribution resistivity response of the earth as a whole, according to the depth coverage of injection currents and equipotentials that are considered homogeneous which provide the same resistance values for the same electrode array. Furthermore, the apparent resistivity value must be processed to be true resistivity for each layer of vertical electrical sounding (VES).

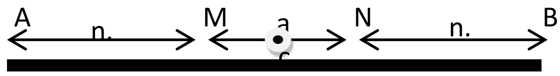

Figure 2: Wenner-Schlumberger configuration arrangement (modified Schlumberger).[13]

Wenner-Schlumberger's configuration electrode arrangement is shown in figure 2. The spacing between electrodes is a, the current electrode stretch (I) is AB, the potential electrode stretch (V) is MN and the vertical electrical sounding point (VES) is c. At the time of data acquisition, a potential electrode (MN) is performed with a fixed electrode spacing i.e. a. The current electrode (AB) is changed according to the multiple of the number n, where: n=1,2, 3, ...,n-1, n. In this study, data acquisition was conducted using a=10m and n=1-20.

Based on the data acquisition results for further data processing to obtain apparent resistivity value (ρa) based on the values a, AB, I and ΔV have been obtained. The apparent resistivity value (ρa) of the Wenner-Schlumberger configuration can be obtained from the equation 2, where in this case s is AB/2.[6]

$$\rho_a = \frac{\pi(s^2)}{a}\frac{\Delta V}{I} \qquad (3)$$

Processing and interpretation of data can use curve matching[2,5,8,12,13]. Distribution of measuring points on Google map can be seen in figure 3.

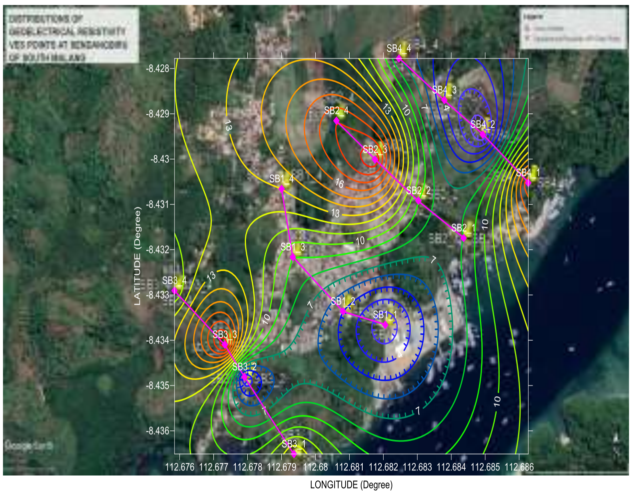

Figure 3: Distribution of measuring points, cross sections of geoelectrical resistivity and topography of Sendangbiru on Google earth maps.

Results and Discussion

Interpretation to obtain aquifers and lithology classes is carried out through the conversion stage of resistivity value of each layer into aquifers as well as lithological classes. The terminology of resistance value conversion to geology and local lithology/aquifer class can be seen in table 2.

Processing and interpretation of data in the form of 2 dimensions were carried out by taking cross sections along the measuring points of vertical electrical sounding (VES) geoelectrical resistivity (table 3).

Table 1
Coordinate of geolelectrical data acquisition point on the coast of Sendangbiru (SB).

S.N.	POINT	LAT. (Degree)	LONG. (Degree)	ALT. (m)
1	SB1_1	-8.43366	112.68206	2
2	SB1_2	-8.43336	112.68081	5
3	SB1_3	-8.43216	112.67933	9
4	SB1_4	-8.43066	112.67900	13
5	SB2_1	-8.43174	112.68436	8
6	SB2_2	-8.43092	112.68303	9
7	SB2_3	-8.43001	112.68175	20
8	SB2_4	-8.42915	112.68062	18
9	SB3_1	-8.43651	112.67937	13
10	SB3_2	-8.43481	112.67791	3
11	SB3_3	-8.43409	112.67733	20
12	SB3_4	-8.43290	112.67585	10
13	SB4_1	-8.43052	112.68627	18
14	SB4_2	-8.42946	112.68493	1
15	SB4_3	-8.42869	112.68380	4
16	SB4_4	-8.42778	112.68246	7

Table 2
Terminology of resistivity value conversion to local geology.

Resistivity	Class	Colour symbol	Description
$\rho \leq 1.5$	0		Alluvium with sea water intrusion
$1.5 < \rho \leq 100$	I		Alluvium (mud, silt, pebble and cobbel (coastal, river and swamp deposits). Good porosity aquifer.
$100 < \rho \leq 1000$	II		Claystone, siltstone, coal and lignite. Enough porosity. Enough aquifer
$1000 < \rho \leq 3000$	III		Interbedded Mudstone, sandstone and conglomerate. Less porosity. Less aquifer
$3000 \leq \rho$	IV		Interbedded claystone and limestone, commonly calcareous. Massive. No porosity. No aquifer/ Acuiclud

Table 3
Cross sections along the measuring points of vertical electrical sounding (VES) geoelectrical resistivity.

S.N.	Cross section names	Points
1	SB1	SB1_1- SB1_2- SB1_3- SB1_4
2	SB2	SB2_1- SB2_2- SB2_3- SB2_4
3	SB3	SB3_1- SB3_2- SB3_3- SB3_4
4	SB4	SB4_1- SB4_2- SB4_3- SB4_4

For Sendangbiru coast, cross section is done on:

1. Cross section SB1: SB1_1- SB1_2- SB1_3- SB1_4
2. Cross section SB2: SB2_1- SB2_2- SB2_3- SB2_4
3. Cross section SB3: SB3_1- SB3_2- SB3_3- SB3_4
4. Cross section SB4: SB4_1- SB4_2- SB4_3- SB4_4

Cross sections of SB1, SB2, SB3 and SB4 can be seen in figure 4, figure 5, figure 6 and figure 7 respectively.

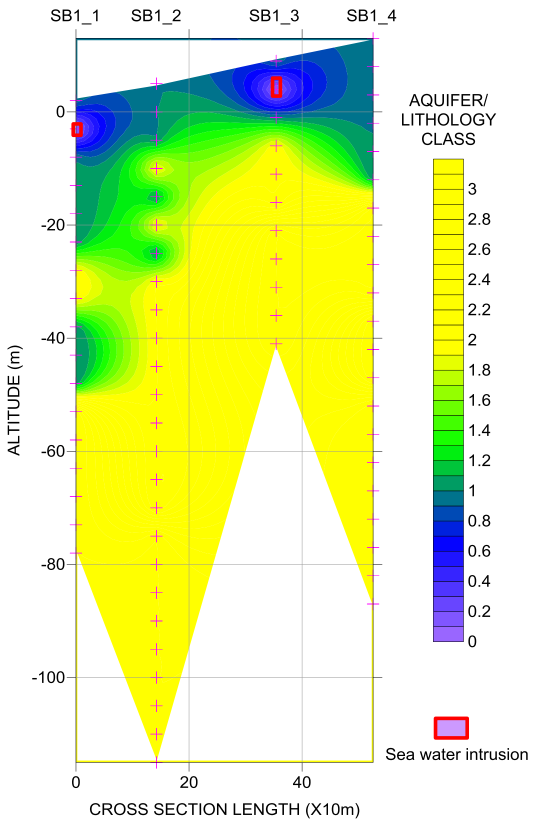

Figure 4: Lithology class cross section of SB1.

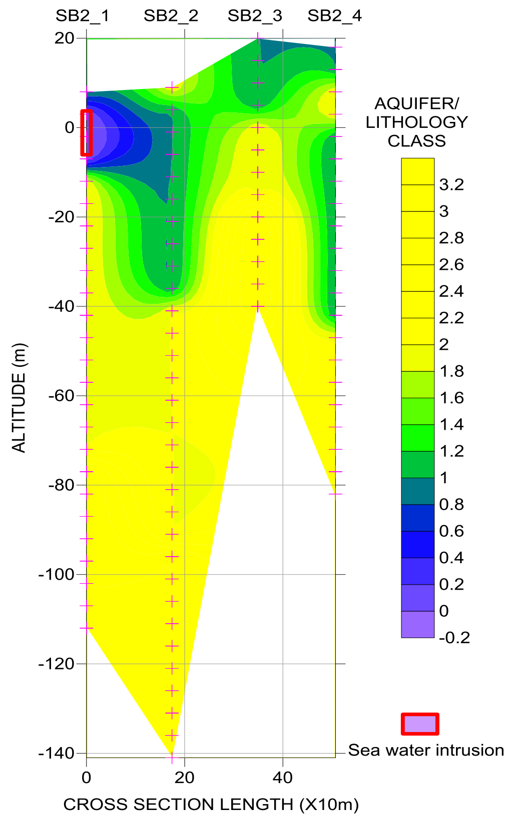

Figure 5: Lithology class cross section of SB2.

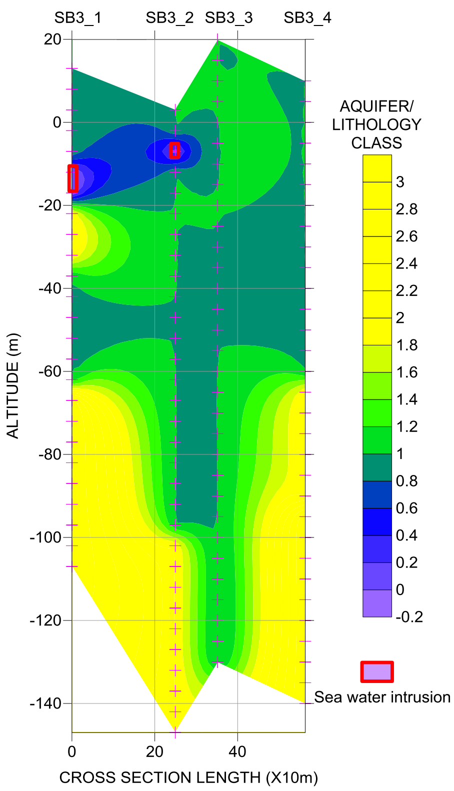

Figure 6: Lithology class cross section of SB3.

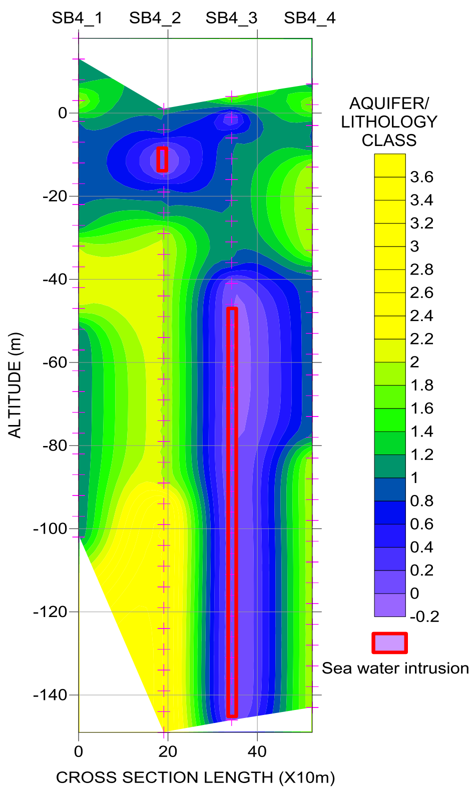

Figure 7: Lithology class cross section of SB4.

There is distribution of measuring points, geoelectric resistivity cross sections and topography on the Google earth map for Sendangbiru locations. The SB1 cross section along the geoelectric measuring points SB1_1- SB1_2- SB1_3- SB1_4 (figure 4) shows the intrusion at a depth of 6m-7m. At depths of 0m - 6m and 7m - 120m, there is no possible intrusion as there is a massive limestone litology (karst) that prevents the intrusion process from occurring.

SB2 cross section along the geoelectric measuring points of SB2_1- SB2_2- SB2_3- SB2_4 (figure 5) shows that the intrusion is at a depth of 6m-8m. At depths of 0m - 6m and 8m - 120m, there is no possible intrusion as there is a massive limestone litology (karst) that prevents the intrusion process from occurring. For the SB3 cross section along the geoelectric measuring points SB3_1- SB3_2- SB3_3- SB3_4 (figure 6) shows that the intrusion is at a depth of 22m - 26m. At depths of 0m - 22m and 26m - 120m, there is no possible intrusion as there is a massive limestone litology (karst) that prevents the intrusion process from occurring. SB4 cross section along the geoelectric measuring points of SB4_1- SB4_2- SB4_3- SB4_4 (figure 7) shows that there is no intrusion at point SB4_1, but at point SB4_2 there is an intrusion at a depth of 5m - 8m as well as at SB4_3 and also at a depth of 43m - 102m.

Conclusion

For Sendangbiru locations, SB1 indicates that the intrusion is at a depth of 6m-7m. For cross section SB2, the intrusion is at a depth of 6m-8m. For cross section SB3, the intrusion is located at a depth of 22m - 26m. The cross section shows that there is no intrusion at the SB4_1 point, but at point SB4_2, there is an intrusion at a depth of 5m - 8m, as well as at the SB4_3 is also at a depth of 43m - 102m.

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