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# Identification of Seawater Intrusion in Kota Lama Semarang and Surrounding Based on Geoelectrical Resistivity Survey

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**Abstract.** Kota Lama Semarang is a tourism potential that causes a high demand for groundwater, which can cause seawater intrusion. Seawater intrusion can affect groundwater quality and soil conditions. This research aimed to determine the depth and distribution of seawater intrusion in the Kota Lama Semarang and surrounding. The research used electrical resistivity tomography (ERT) and vertical electrical sounding (VES). Geoelectrical resistivity surveyed consist of 4 ERT lines and 3 VES lines with a line length was 100 to 160 m. Lines were scattered north and south of the Kota Lama to determine the distribution of seawater intrusion. Inversion processing used Progress for VES and Res2DInv for ERT. The content of chloride as well in Kota Lama was measured as supporting data. At this location it was estimated that it has 3 layers: top soil, sand and sandy clay. The sand layer at a depth of 3 to 11 m was the layer affected by seawater intrusion. Seawater intrusion on the north side was higher than on the south side. This was indicated by the lower resistivity value of the groundwater layer on the north side. The resistivity value of the groundwater layer on the north side was  $0.96 \Omega\text{m}$  while the south side was  $3.76 \Omega\text{m}$ . This result was appropriate to the chloride content which indicates a higher concentration on the north side of the Kota Lama Semarang.

## 1. Introduction

Seawater intrusion is a global problem affecting groundwater quality and soil conditions along coastlines [1]. Seawater intrusion is the process of entering seawater into freshwater aquifers. So the groundwater, which was originally fresh water becomes brackish water and even saline water. This causes a decrease in groundwater quality in the area [2]. Groundwater is considered as one of the most suitable water sources to meet the needs of most pure water [3][4].

Kota Lama Semarang has good tourism potential to be nominated for UNESCO World Heritage Sites [5]. The area, which is located in the north Semarang district, has a western historic building [6][7]. The growth of Semarang City has increased the demand for water [8]. The step that many people take is to take groundwater from unconfined aquifers. Groundwater exploitation is not only carried out through dug wells, but also drilled wells that can reach deeper aquifers. Groundwater exploitation is mainly for industrial activities such as hotels, hospitals, etc. Overexploitation of groundwater can lead to subsidence and seawater intrusion [9][10]. Coastal aquifers are fragile, because they are generally in direct contact with seawater, which is very vulnerable to seawater intrusion [11].

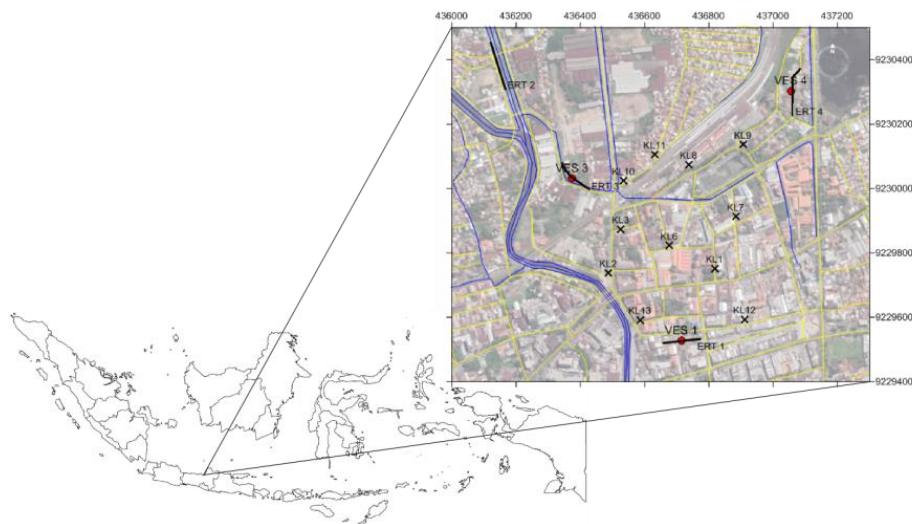
Seawater can affect electrical properties in the form of higher conductivity than freshwater [12]. The difference of the electrical conductivity of freshwater and saltwater is very significant, and therefore, the geoelectrical resistivity method is suitable for determining seawater intrusion in coastal areas [13].



Based on the description above, the purpose of this study was to determine the depth and distribution of seawater intrusion in the Kota Lama Semarang and its surroundings using the geoelectrical resistivity method with the Schlumberger array and measurement of Chloride content.

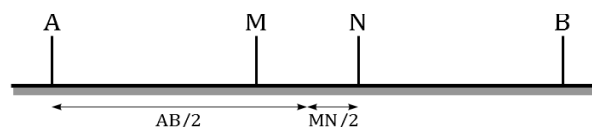
## 2. Method

This research began with studying hydrology and geological condition. Then, measured the chloride content in groundwater as well in Kota Lama Semarang. Next, the geoelectrical resistivity survey used Electrical Resistivity Tomography and Vertical Electrical Sounding with Schlumberger array. Lines were scattered north and south of the Kota Lama to determine the distribution of seawater intrusion. Line 1 was on the south side and lines 2, 3 and 4 on the north side of the Kota Lama Semarang, as can be seen in Figure 1. Line 1 was on the South Parking complex consisting of ERT and VES along 120 m. Line 2 was on Jl. Kom Yos Sudarso consisting of ERT along 150 m. Line 3 was on *Vereenigde Javasche Houthandel Maatschappij* “ex Java wood trading office” complex consisting of ERT along 120 m and VES along 100 m. Line 4 was on Jl. Tawangsari consisting of ERT along 150 m and VES along 160 m.



**Figure 1.** Map of research location, VES points and ERT lines.

The geoelectrical resistivity survey conducted on March 20 to 21, 2021. This survey used Resistivity Meter OYO Mc Ohm. The ERT survey used a 10 meter electrode spacing unit. The data were measured manually according to a Schlumberger array. The data recorded were current ( $I_{AB}$ ) and voltage ( $V_{MN}$ ). After the geoelectrical resistivity acquisition, it was continued by recording the VES point measurement and the position of each ERT electrode using GPS. The basic principle of the geoelectrical resistivity method is to inject electric current into the earth and then measure the electric potential. The purpose of this method is to obtain information about the structure based on the difference in resistivity values [14]. In Schlumberger configuration, two electrodes are positioned symmetrically along a straight line as depicted in Figure 2. The current Electrodes (AB) are outside, whereas the Potential Electrodes (MN) are inside. In order to change the depth range of measurement, the current electrodes are moved outside, while the potential electrodes are fixed [15].



**Figure 2.** Schlumberger array electrode position.

The geometry factor for the Schlumberger array is written in equation (1).

$$K = \pi \frac{\left(\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2\right)}{MN} \quad (1)$$

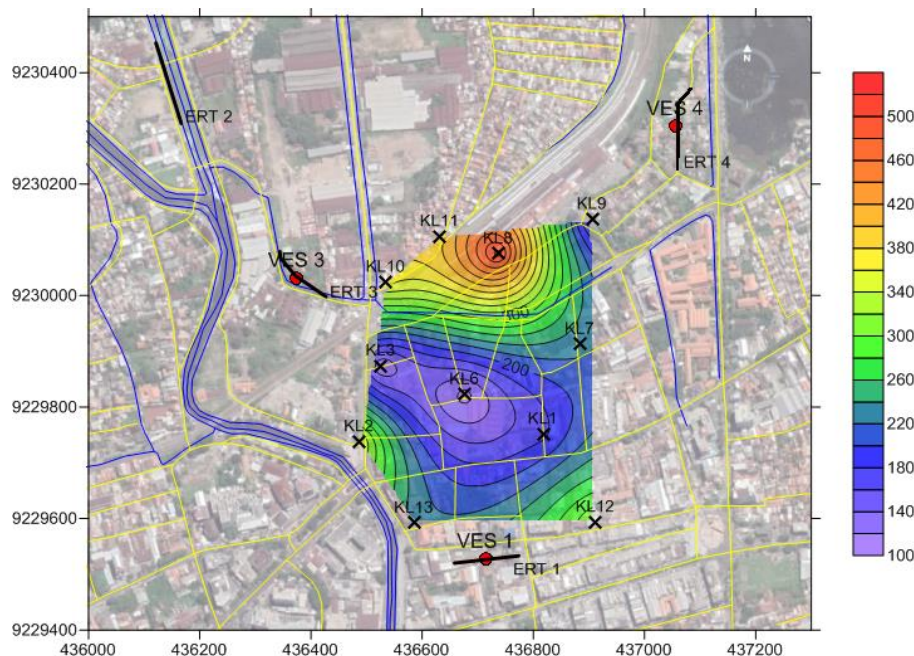
Preliminary data processing used Microsoft Excel software to obtain apparent resistivity value. The apparent resistivity was calculated using equation (2). Inversion processing used software progress for VES and software Res2DInv for ERT. The apparent resistivity value converted using inversion software will be correlated with direct measurements of groundwater samples taken [16]. During the processing stage, the electrode elevation data was entered in the inversion process so that the depth displayed in the resistivity profile refers to the mean sea level [17].

$$\rho_a = K \frac{\Delta V}{I} \quad (2)$$

The difference in resistivity values was then used for identification, with basic knowledge of resistivity aspects such as geological conditions to interpret subsurface conditions [18]. Seawater intrusion will be indicated with a very low resistivity value [19].

### 3. Result and Discussion

Chloride content measurements were carried out as an early indication of seawater intrusion of the Kota Lama Semarang. Groundwater sampling was taken from 11 wells in the area. The results of the measurement of chloride content in groundwater samples are presented in Figure 3. From the results shown in Figure 3, there were seven groundwater samples with chloride ion content of more than 250mg/l, which is shown in green to red. Seventh groundwater samples had chloride ion levels of more than 250 mg/l that are in KL1, KL2, KL7, KL 8, KL 10, KL 11 and KL 12. Chloride content can indicate seawater intrusion [20][21]. From the image of the distribution of chloride content, it is known that the northern region has a higher content than the southern region. This indicates that the northern region sea water intrusion is higher than the southern region.



**Figure 3.** Chloride Distribution

A vertical electrical sounding survey was conducted to determine the depth of seawater intrusion in Kota Lama Semarang. The results of the inversion process can be seen in table 1.

VES 1 was in the south parking lot of the Kota Lama Semarang. At this location it is estimated that it has 3 types of layers: top soil, sand and sandy clay. Top soil layer with a resistivity value of 81.30  $\Omega\text{m}$  with a thickness of 0.89 m. Sand layer with a resistivity value of 3.76 to 23.96  $\Omega\text{m}$ . Sand with a resistivity value of 3.76  $\Omega\text{m}$  is sand saturated with water. This resistivity value indicates the intrusion of sea water with low concentration. This layer was at a depth of 3.24 m. Sandy clay layer with a resistivity value of 19.60  $\Omega\text{m}$  was at a depth of 11.16 m.

VES 3 was in *Vereenigde Javasche Houthandel Maatschappij* “ex Java wood trading office” complex. At this location it is estimated that it has 3 types of layers: top soil, sand and sandy clay. Top soil layer with a resistivity value of 51.45  $\Omega\text{m}$  with a thickness of 0.83 m. Sand layer with a resistivity value of 0.96 and 13.88  $\Omega\text{m}$ . Sand with a resistivity value of 0.96  $\Omega\text{m}$  is sand saturated with water. This resistivity value indicates the intrusion of sea water with high concentration because it has a resistivity value of less than 1  $\Omega\text{m}$ . This layer was at a depth of 2.99 m. Sandy clay layer with a resistivity value of 16.79  $\Omega\text{m}$  was at a depth of 11.84 m.

VES 4 was on Jl. Tawang Sari. At this location it is estimated that it has 4 types of layers: top soil, sand and sandy clay and. Top soil layer with a resistivity value of 12.97  $\Omega\text{m}$  with a thickness of 0.86 m. Sand layer with a resistivity value of 0.96 and 22.14  $\Omega\text{m}$ . Sand with a resistivity value of 0.96  $\Omega\text{m}$  is sand saturated with water. This resistivity value indicates the intrusion of sea water with high concentration because it has a resistivity value of less than 1  $\Omega\text{m}$ . This layer was at a depth of 2.15 m. Sandy clay layer with a resistivity value of 15.40  $\Omega\text{m}$  was at a depth of 4.42 m. Sand layer saturated by water with a resistivity value of 2.18  $\Omega\text{m}$  was at a depth of 12.02 m

**Table 1.** Table type of layer, depth and resistivity value

VES 1		VES 3		VES 4		Lithology
depth	rho	depth	rho	depth	rho	
0	81.30	0	51.45	0	12.97	Top Soil
0.89	23.96	0.83	13.88	0.86	22.14	Sand and Gravel
3.42	3.76	2.99	0.96	2.15	0.96	Groundwater
11.16	19.60	11.84	16.79	4.42	15.40	Sandy Clay
				12.02	2.18	Groundwater

Electrical resistivity tomography survey was conducted to determine the distribution of seawater intrusion in Kota Lama Semarang. An ERT survey in Schlumberger array with an electrode distance of 10 m was used for profiling. Four ERT lines were obtained to a penetration depth of about 21 to 27 m with a total length between 120 to 150 m.

Line 1 was in the south parking lot of the Kota Lama Semarang. The results of the inversion on this line obtained a resistivity value between 2.87 to 12.01  $\Omega\text{m}$  which can be seen in Figure 4. Line 2 was on Jl. Kom Yos Sudarso. The results of the inversion on this line obtained a resistivity value between 0.28 to 9.03  $\Omega\text{m}$  which can be seen in Figure 5. Line 3 was in *Vereenigde Javasche Houthandel Maatschappij* “ex Java wood trading office” complex. The results of the inversion on this line obtained a resistivity value between 0.81 to 2.59  $\Omega\text{m}$  which can be seen in Figure 6. Line 4 was on Jl. Tawang Sari. The results of the inversion on this line obtained a resistivity value between 0.27 to 30.29  $\Omega\text{m}$  which can be seen in Figure 7. Seawater intrusion was detected on Line 2, 3 and 4. Seawater intrusion was indicated by a value less than 1  $\Omega\text{m}$  shown in blue [22].

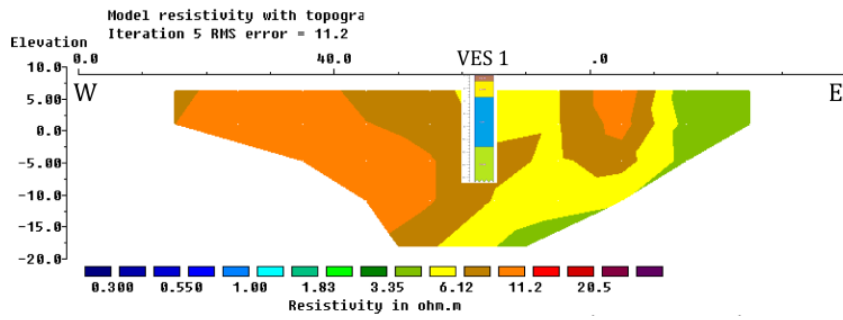


Figure 4. The 2D subsurface resistivity profiling of line 1

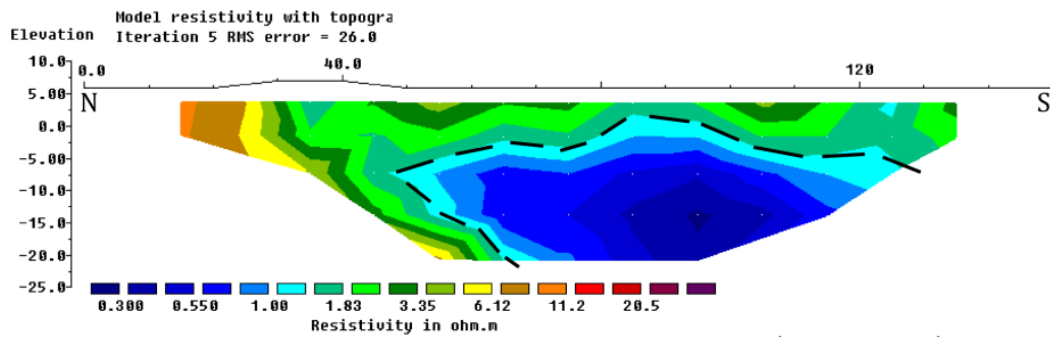


Figure 5. The 2D subsurface resistivity profiling of line 2

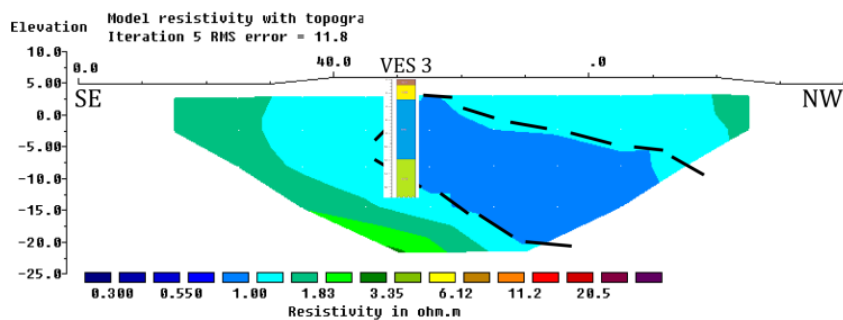


Figure 6. The 2D subsurface resistivity profiling of line 3

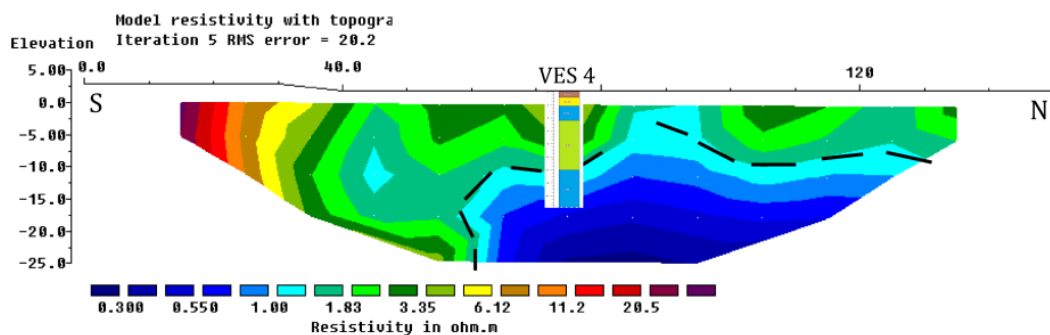


Figure 7. The 2D subsurface resistivity profiling of line 4

Form the resistivity survey and chloride content measurement, seawater intrusion on the north side was higher than on the south side.

#### 4. Conclusion

Seawater intrusion occurred in the sand layer at a depth of 3 to 11 m. The resistivity value of this layer was 0.96 to 3.76  $\Omega\text{m}$ . Seawater intrusion on the north side was higher than on the south side. This was indicated by the lower resistivity value of the groundwater layer on the north side. The resistivity value of the groundwater layer on the north side was 0.96  $\Omega\text{m}$  while the south side was 3.76  $\Omega\text{m}$ . This result was consistent with the chloride content which indicates a higher concentration on the north side of the Kota Lama Semarang.

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