Identification of Saline Water and Fluid Flow in Tanjung Priok and Koja North Jakarta Using Geoelectric Method

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Abstract. To date the cause of saline water in Jakarta area is still debated. One opinion says that salty ground water is caused by sea water intrusion. Other opinions stated that the salty water appears from connate water. The objective of this study is determining the causes of saline water in North Jakarta, especially in Tanjung Priok and Koja. The method used to describe the subsurface fluid flow and resistivity spread is geoelectric method. The method consists of SP (self potential) for fluid flow and resistivity for distribution of subsurface saline water. The data is processed using RES2DINV software and interpreted with processed SP to produce a cross-section map. The results of these two methods are also supported by geological data and wells data samples as well as gravity data in the form of FHD (first horizontal derivative). The results of the resistivity indicate the presence of saline water at a depth of 5-10 meters which is a shallow aquifer. The saline water in this study area most likely caused by the sea intrusion as the SP results show that the subsurface groundwater flows from North to South.

1. Introduction

Jakarta is the capital city of Indonesia which is growing very rapidly. In 2015, Jakarta had already a population of 10,177,924 people with a population density of 15,328 people/km² [1]. This makes Jakarta has a lot of water needs. The large number of population also causes the reduction of open land that has the potential for recharge area [2]. The reduced zone of water absorption, the growing groundwater exploitation, and the heavy burden of development caused the void of water in the subsurface rock pores. The balance of hydrostatic pressure between saltwater and freshwater in the coastal area, therefore, is disturbed, so the movement of water from sea to land makes it possible [3].

This situation makes groundwater experts still debating the causes of saltwater in Jakarta. The first opinion of salty ground water is caused by sea water intrusion. And the other ones are not caused by sea water intrusion [4]. They said the salty water appears from connate water.

To identify the cause of saltwater in the Jakarta area whether by intrusion or not, it is necessary to have geoelectric measurements. Geoelectric method is a method commonly used to measure the direction of fluid flow and the distribution of subsurface resistive rocks. Geoelectric measurements carried out in Tanjung Priok and Koja in the form of SP methods for fluid flow and resistivity methods for saltwater distribution maps.

2. Geological Review

The regional geology of Jakarta during the Middle Miocene was in the shallow sea phase and limestone dominating of Parigi Formation was deposited. During the late Miocene, clay sandy areas...
settled in what is now a coastal area. Then, in the Pliocene phase the magmatic arc moves to the middle of Java. Continued in the Pliocene-Pleistocene phase where Jakarta became the foot of the mountain due to West Java being lifted. The material that led to Jakarta was deposited and became the alluvium fan deposit in the river that flowed into the Java Sea [5].

Geological map of Jakarta Bay and Jakarta Coast, which is the area of the study location, is illustrated in Figure 1. The North Jakarta is dominated by alluvial rock which consists of clay, silt, sand, gravel, pebble, and boulder. In some areas the rocks are beach ridge deposits with course sand and well sorted. In study area (the red box in Figure 1) there is shallow marine deposits with alternating of silt, clay and tuff.

**Figure 1.** Geological Map of Jakarta Bay and Jakarta Coast [6]. The red box is the study area.

### 3. Method

There are 53 groundwater sampling data obtained from the areas of Tanjung Priok and Koja, North Jakarta. The distribution of sampling data locations is shown in Figure 2. The groundwater samples are measured in terms of salinity, pH and conductivity.

The data used in this study are geoelectric data with 4 lines in which the location is in accordance with Figure 2. Line 1 and line 2 are laid on the left part of Figure 2 as the Tanjung Priok area. While the line 3 and 4 on the right ones, the Koja area. The geoelectric data are acquired using ARES-G4 instrument. For each line a long cable of 4 x 40 m is laid out with a distance between the electrodes is 5 meters. The length of each line is 160 m for location 1, 2, 3 and 120 m for line 4. The total number of electrodes of the entire line is 120 electrodes. Measurements are made implementing a dipole-dipole configuration.

The geoelectric data are then proceed by using RES2DINV software to create a resistivity and potential section along the line.
4. Result and Discussion

4.1. Well Data

From the conductivity map in Figure 3 there are high conductivity areas in the North Koja and part of Tanjung Priok. Both areas are located along the coastal line. The high conductivity indicates the present of contamination within the water samples. Considering the area of measurement, the increase in conductivity can be caused by either the high content of salt or metals.

The maps of salinity and pH level are made as shown in Figure 4. The salinity map is created to show how high the salt content levels are in the study area. While a pH distribution map is performed to measure the spread of existing metals.

The pH map in Figure 4 shows that the Koja region has relatively high value rather than the Tanjung Priok ones. So, the Koja area is probably more contaminated by metal elements from
industrial waste. However, the salinity map shows that both areas Tanjung Priok and Koja have high salinity. The two circle interesting areas are saline areas.

Figure 4. The maps of (a) pH and (b) salinity level in the study area based on well data sampling.

The salinity results show the influence of salinity levels in the Koja and Tanjung Priok areas. The pattern formed is very similar to the map of the conductivity results compared to the pH results. The two maps of salinity and conductivity are very similar. It is suspected that the high conductivity in both areas is more influenced by the salinity content rather than the effect of metal content.

This salinity map is also similar to the geological map in Figure 1 in parts of Tanjung Priok which has salty area. The area is geologically indicated as a shallow marine sediment area. Also in northern of Koja area, the high conductivity and high salinity may be associated with the presence of geologically coastal sediment deposits. Giving rise to something interest here, is the source of the cause of saltwater in the region is likely from the deposition of saltwater from ancient times (as connate water) or derived from intrusion of sea water.

Topographically, the study area has an increasingly lower trend northwards. Even in the area of Tanjung Priok, the mainland along the beach is below sea level. Koja also situated in the same thing, the elevation of some northern areas is below sea level. The water table, therefore, is also below sea water. The area below sea level is also of more concern in determining the measurement line. When an area has a topography lower than the sea level, the sea water most probably intrude into the land. The Ghyben-Herzberg relationship says the lower the watertable of an area, the greater the tendency to experience intrusion [7].

4.2. Geoelectric Section

Figure 5 shows the distribution of subsurface resistivity in the line 1 and the line 2 (Tanjung Priok) and line 3 and line 4 (in Koja area). The two sections can be categorized into 3 types of layers, namely:

a. A layer of clay or sand (green) which contain brackish/saltwater with resistivity ranging of 1-5 $\Omega$m.

b. Shallow aquifer layer (blue) which is indicated to contain high saltwater with resistivity < 1 $\Omega$m.

c. Layer of sandstone or clay (yellow to red) with resistivity ranging of 6-600 $\Omega$m.

The electric characteristic along the line 1 and 2 of Tanjung Priok is relatively more resistive than in line 3 and 4 of Koja. In the Koja’s line, all areas almost conductive area. It makes sense and reasonable as the area has the aquifer with high value of pH and salinity (see Figure 4). The area most probably also associated with the coastal sediment deposit. In the Tanjung Priok’s line oppositely, the area relatively more resistive. On the top surface, the higher resistive layer may be caused by the existence of weather rock. However, the conductive layers are identified at very shallow depth along of line, which most likely associated with the saline water rather than metals material. Overall, the
resistivity results are justified by the well data samplings. The salted aquifers are found at depths of around 1-15 m. The aquifers are shallow aquifers.

![Resistivity section](image)

**Figure 5.** Resistivity section of (a) line 1 and line 2 (Tanjung Priok), and (b) line 3 and line 4 (Koja).

To see where the saline water come from, the SP results may described the phenomena. The points on Figure 6 show the position of the electrodes installed at the measurement. The red dot is the reference point of the self potential (SP) measurement carried out on each line.

Conceptually, the fluid flows towards the low SP anomaly [8, 9]. The results of Self-Potential show that the fluid flows from North to South or landward on lines 1, 2 and 3, whereas on line 4, the surface fluid flows from South to North or towards the sea. All SP data can be said that the subsurface fluid tends to flow from North to the South.

![Self-Potential section maps](image)

**Figure 6.** The SP section maps at (a) line 1, (b) line 2, (c) line 3, and (d) line 4.

The FHD gravity data is also indicated the fluid flows from North to the South as shown in Figure 7. Areas with high FHD value are suspected to be the place of salt deposit as a result of sea water intrusion from the north. The salt deposits will create a contrasting density towards the surrounding and form as an anomalous zone, so that it is manifested in the FHD map of gravity as a high-value region. Therefore, the FHD maps can also be associated with subsurface fluid flow. The fluid flows...
towards areas with high FHD value. The model of subsurface fluid flow in the study area is shown in Figure 7. The groundwater flow in the south of Koja is still south-north orientation. The hydrostatic pressure in this area looks still large enough relative to the marine hydrostatic pressure.

Figure 7. Subsurface fluid flow model according to the geoelectric and gravity data.

5. Conclusion
Based on geoelectric data, in the Tanjung Priok and Koja areas there is a distribution of saltwater below the surface with a depth of aquifers about 1-15 m. As the SP and gravity data show subsurface fluid flow in the (Tanjung Priok and Koja) study area leads from north to south, the saltwater here most likely caused by sea water intrusion. The intrusions here have reached more than 1.5 km from the shoreline.

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