Horizontal gradient analysis of gravity data for subsurface fluid flow identification (case study: cilincing, north jakarta)

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Abstract. Jakarta is a large city with a 10.37 million population. Most of the clean water needs are provided via groundwater. This might be a problem for some areas with groundwater conditions such as brine, or even salty water. The salt-water issue in Jakarta is not uncommon. Many researchers have conducted their studies on this topic from many perspectives. They are all divided into 2 main general conclusions, saltwater happens because of intrusion and saltwater is there because it is connate water. This study aims to give a new perspective on understanding the salt-water issue. Methods used for this study are gravity measurement to get a horizontal gradient value. The other is groundwater well sampling to measure the value of pH, salinity, conductivity, and water table elevation. These methods will be comprehensively interpreted to get the direction of subsurface fluid flow. Results from salinity and conductivity of groundwater show more salinity and conductivity in the North direction and less on the South one. Gravity data and the geological map also suggest that there is a fluid flow coming from North East to South West. All of these methods used in this study have come to one conclusion, there is water flowing from the sea to the land, therefore there is a most likely saltwater intrusion on the region where this study is conducted.

1. Introduction
Jakarta, according to the last census, has 10.37 million citizens [1]. This amount of these citizens needs clean and freshwater for their lives. Most of the water from Jakarta comes from groundwater [2].

Groundwater in Jakarta comes from the Great Jakarta Groundwater Basin which the accumulation of 14 rivers flowing into Jakarta, Bogor, Depok, Tangerang, and Bekasi [3].

Groundwater extraction, if too much, can disturb the hydrostatical balance between freshwater and saltwater and in turn, create saltwater intrusion [3]. The saltwater problem in Jakarta is proven to be debatable among researchers from many expertise. Although the saltwater is real, it is still being questioned whether it comes from saltwater intrusion or from others. Some researchers found that saltwater intrusion theory is true and it even goes as far as 25km from the sea [4]. Whereas some other researchers stated that saltwater in Jakarta comes from connate water that trapped inside the formation of rocks a long time ago [5].

This study aims to add a perspective on understanding the origin of saltwater in Jakarta. Methods used in this study are groundwater sampling and gravity data measurement to get the horizontal gradient value. Results from each method will be combined to make the model of groundwater flow confirm whether there is a saltwater intrusion or not.

The location in this study takes place in Cilincing Region, North Jakarta. According to the geological map in Figure 1, this region consists of alluvium and beach ridge deposit. Alluvium consists of mostly clay, silt, sand, gravel, and pebble. Beach ridge deposit consists of fine to coarse sand and mollusk shells.
that deposited in the study area by wind and formed a sand dune [6]. If there is a saltwater intrusion, it is highly believed to flow through the sand rather than the alluvium because sand has higher in both porosity and permeability, thus, saltwater will flow easier [7].

2. Methods

Methods used in this study are started from data acquisition at the location. One of the data gathered is groundwater samples taken from wells around the location of the study. Water samples are measured for pH, salinity, conductivity, and water table elevation. The other data is gravity data measured using CG5 Scintrex gravimeter. All the data are then made into a contour map to visualize the distribution. Each map is interpreted individually and together to get comprehensive and integrated interpretation about the subsurface condition at the study area, thus, fluid flow can be identified and confirmed whether there is a saltwater intrusion or not. There is also a self-potential geoelectrical method as a supporting method to confirm the fluid flow in the subsurface.

3. Results and discussion

3.1. Groundwater data

The Groundwater samples data are then made into 4 contour maps based on 4 characteristics; water table elevation, conductivity, pH, and salinity of the groundwater. Figure 2a shows the water table elevation. It varies from -0.5m to 6m. The pattern is relatively high in the South and getting lower in the North. Figure 2b shows the map of the pH of the groundwater sample. The values of pH vary from 6.5 to 8.4, which are normal and basic. High pH might indicate a metal content in the water but it needs further and more detail measurement.
Figure 2. Contour map of (a) water table elevation and (b) pH of groundwater sample.

The map of conductivity of the groundwater sample is provided in Figure 3a. It varies between 200 to 4800 micro Siemens/cm. On the Northside of the map, the conductivity value is much higher than on the South ones. High conductivity might be caused by either a high level of metal or a high level of salt ion in the water.

The other map is the salinity contour map as shown in Figure 3b. The values widely vary between 0-2500mg/L with 0 being freshwater. The pattern of salinity map shows there is a very saline area in the Northeast rather than the Southwest. It might suggest that high content of salt comes from the sea, Northeast to Southwest, but it is still needed to be confirmed by gravity data and self-potential data.

Figure 3. Contour map of (a) conductivity and (b) salinity.

From both the Figure 2 and Figure 3, when both conductivity and salinity contour map is shown together, there is some similarity in the pattern marked in the red circle, high in the North-East and low in the South-West. The similarity in the pattern only found between the conductivity and the salinity map, not in the pH map. Therefore, the high conductivity in this area highly indicates high salt content rather than metal content. The question is, where the salt originated from?
3.2. **Gravity data**

The horizontal gradient of gravity data is the lateral change of the gravity value [8]. The value indicates the trend of high or low gravity body anomalies, so it may show the border between bodies of gravity anomalies. The border area is usually represented in the maximum value of the horizontal gradient [9]. Figure 4 shows the map of the horizontal gradient varies between 0.0001 to 0.0029 mgal/m.

![Map of the horizontal gradient of gravity data](image1.jpg)

**Figure 4.** Map of the horizontal gradient of gravity data

Horizontal Gradient of gravity data has a relatively low anomaly in the Northeast and high anomaly in the Southwest. The high anomaly may indicate the accumulation of saltwater flowing underground that suggest saltwater has been flown into that direction. Based on the gravity data, the fluid flow comes from the Northeast due to Southwest. This is supported by the salinity data that shows that the salinity region is higher in the Northeast and gets lower to the Southwest direction. The pattern of fluid flow also supported by a geological map that suggests fluid highly flows through sand rather than alluvium. Thus, the fluid flow model is provided in Figure 5, showing fluid flow comes from Northeast to Southwest and accumulates somewhere in the center. The fluid is highly believed to be saltwater, confirmed by salinity and conductivity map.

![Fluid flow model](image2.jpg)

**Figure 5.** Fluid flow suggests by salinity and horizontal gradient map drawn in black arrow.
Another data supporting the fluid flow model from gravity is self-potential. As provided in Figure 6, the equipotential maps in line 1 to line 3 show that high potential in the North and low potential in the South. In the self-potential method, fluid flows from high potential to low potential due to it carries ion and accumulates the ion somewhere. This causes a contrast in potential value, thus, high contrast is where the fluid comes from and it flows to the low contrast. In this study, the fluid being salt water flowing from the sea to the land [10]. This method confirms the fluid flow model of gravity data.

4. Conclusion
Water table elevation relatively high in the South and getting low to the North. The pH value of the water in the study area ranges from 6.5 to 8.4. Water conductivity contour matches with salinity contour, implying that the conductivity of the water is believed from the high content of salt. Analysis and interpretation from both gravity data and groundwater data, supported by geological map, indicates a fluid flow coming relatively from North to South, which is from sea to land. Saltwater in the location of the study is indeed come from saltwater intrusion.

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