Identification of Subsurface Water Flow Using Gradient Horizontal Gravity Data in Tanjung Priok and Koja, North Jakarta

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Abstract. The presence of saline or salt water in the Jakarta groundwater aquifer is still widely debated by various geologists and groundwater experts. This study intends to identify the cause of the high salinity of groundwater at Tanjung Priok and Koja, North Jakarta. The First Horizontal Derivative (FHD) method of gravity data is applied to identify the direction of subsurface fluid flow. It is also supported by groundwater sample data and self potential (SP) data. The direction of fluid flow on the FHD contour map is indicated from low to high FHD value. From gravity data, Bouguer density values obtained in the study area were 2.12 gr/cm³. This study focuses on surface aquifers so that it is necessary to separate regional and residual anomalies. The results show that the direction of fluid flow is from north to south, there is a high FHD value that is distributed around the coordinates (709000, 9322000) which may indicate as the salt depositions of sea water intrusion.

1. Introduction
Jakarta is a metropolitan city as well as a centre of government and the country's economy. This makes Jakarta rapidly growth both in terms of development and the population of Jakarta itself. Jakarta's population increase from year to year causes an increase in the demand for water resources both in quality and quantity, an increase in land use, and an increase in population activities. The situation can have an impact on the subsurface geological conditions, decrease in density [1]. The reduced rock density has the potential to be a source of disasters such as sea water intrusion [2].

The presence of salt water in some areas of Jakarta, especially North Jakarta is still debated by researchers [3, 4]. To find out the cause of high levels of salt water in the North Jakarta, a study was conducted to measure salinity, conductivity, pH and watertable levels in groundwater samples as well as trace directions of subsurface fluid flow using the First Horizontal Derivative (FHD) method of gravity data.

2. Methodology

2.1. Gravity Gradiometry
The gradiometry data acquired by city-scale gravity survey. Bouguer density can be obtained by gradient method that requires two observed gravities between two different heights in gradiometric measurements system [5]. Mathematically, the Simple Bouguer Anomaly is given by :
\[ SBA = g_{obs} - g_n + h(0.3085 - 0.04192 \rho) + \text{TC} \]  
\[ g_{obs1} = SBA + g_n - h_1(0.3085 - 0.04192 \rho) + \text{TC} \]  
\[ g_{obs2} = SBA + g_n - h_2(0.3085 - 0.04192 \rho) + \text{TC} \]

If the two equation above are disputed, a straight line equation is obtained between \( \Delta h \) and \( \Delta g_{obs} \), the linear equation is:

\[ \Delta g_{obs} = \Delta h(0.04192 \rho - 0.3085) + \Delta SBA \]

2.2. Spectrum Analysis and Moving Average

Spectrum analysis is used to separate regional and residual anomalies. The separation is performed when the gravity data was transformed from spatial to frequency domain by using Fourier Transform [6]. The Fourier Transform result is:

\[ G(f) = \sqrt{\frac{\pi}{2}} \beta e^{-Dk} \]

\[ \ln[G(f)] = -Dk + \ln\left( \frac{\pi}{\sqrt{2}} \beta \right) \]

Equation 5 and 6 explain the logarithmic plot of \( G(f) \) to frequency (\( k \)) has a depth (\( D \)) as gradient. There is a value of \( k \), called cut-off frequency (\( k_{co} \)), which separates regional and residual body anomaly. By using \( k_{co} \), a suitable window size can be determined to obtain regional anomaly and finally calculate the residual anomaly. The size of window \( N \) can be expressed in:

\[ N = \frac{2\pi}{k\Delta x} \]

where \( \Delta x \) is distance between station.

2.3. First Horizontal Derivative

First Horizontal Derivative (FHD) is a method used to determine the density contrast limits (anomalies) of a gravity data [7]. The principle of processing this data using the following equation:

\[ |H(x, y)| = \sqrt{\left( \frac{\partial G}{\partial x} \right)^2 + \left( \frac{\partial G}{\partial y} \right)^2} \]
3. Results and Discussion

3.1. Bouguer Density

From Figure 1, the Bouguer density value can be obtained as:

\[ m = (0.04192\rho - 0.3085) \]

\[ \rho = \frac{-0.219505 + 0.3085}{0.04192} = 2.12 \text{ g/cm}^3 \]

3.2. Regional and Residual Anomaly

Figure 1. \( \Delta g \) vs \( \Delta h \) graph for calculating Bouguer density.

Figure 2. Regional anomaly contour map.
There is a high residual value in the Northern part of Tanjung Priok shown in Figure 3. The anomaly areas have been drawn clearly on regional map of Figure 2. These locations are also stated in the regional geological map of Jakarta as shallow sea deposits [8, 9].

3.3. First Horizontal Derivative (FHD) Map

Figure 4 shows an area with very contrasting subsurface rock density which has high gravity value. The area may represent the high density zone, which is most likely an area of salt depositions. This area is also verified by groundwater sample data to have high salinity and electrical conductivity (see Figure 5). High conductivity usually caused by either high in salt content or metal content. It might be associated with whether high salinity levels, the presence of shallow marine deposits, or the presence of waste metal content. However, the high conductivity seems more caused by salt content rather than metal content as the pH value is low enough. The high value of pH may correlate with industrial waste where there are many industries.
Figure 5. Map distribution of salinity, pH, conductivity, and watertable of North Jakarta groundwater in 2019.

The high salinity value may indicate that the zone has either occurred intrusion of sea water or connate water that was planted millions years ago. The North Jakarta geological map at the Northern part of Tanjung Priok shows there is a shallow sea sediment that has the same shape as the Northern part of the salinity contour map of Figure 5. To answer where the saline water in the Tanjung Priok and Koja areas comes from, the SP data might be considered for this.

SP data, acquired at 3 lanes in the zone of interest, indicate that there is a subsurface groundwater flow from North to South (see Figure 6). Hence, salt deposits that cause salty groundwater in the study area allegedly caused by intrusion of sea water to the mainland. Low hydrostatic pressure on land due to excessive exploitation of groundwater, may be the cause of sea water intrusion. Sea water which has a higher density and concentration than groundwater, is also a parameter that causes sea water intrusion. The intrusion tends to occur in shallow marine sedimentary rocks.
4. Conclusion
First Horizontal Derivative (FHD) method of gravity data can detect traces of subsurface fluid flow. The data gravity results supported by some physical parameter of groundwater sample data show that sea water intrusion has occurred in the northern part of Tanjung Priok and Koja areas of North Jakarta.

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