Geophysical Approach for Assessment of Seawater Intrusion in the Coastal Aquifer of Bandar Lampung, Indonesia

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Abstract. Overexploitation in 1980-2000 caused a lot of loss of groundwater in the aquifer coastal of Bandar Lampung. Groundwater has been degraded with increasing salinity due to the intrusion of seawater. In 2013, the intrusion has extended 400 m from the coastline. Subsurface geological mapping is carried out with the aim of examining the material constituents of alluvial formations and the ability to transfer seawater to land. Combined research through 3 well exploration, combined with 3 geoelectric tomography and 51 points of gravity. The gravity method used to map the existence of structures that can connect coastal aquifers and land aquifers. Geoelectric tomography to map the presence of aquifers and low resistivity zones by seawater intrusion. The coastline has relatively shallow aquifers at a depth of 2 - 10 m in a sand layer with coral inserts, while the lower part is composed of silt and clay. The aquifer has experienced a decrease in resistivity of fewer than 10 ohms m appears in the three circular patterns, caused by seawater. In addition to the permeable zone of shallow aquifers, there is a northwest southeast trending structure, which can be channeling seawater to land aquifers.

Keywords: coastal aquifer, intrusion, geophysics, Bandar Lampung

1. Introduction

Since the Dutch colonial period, the Bandar Lampung coast has been the gateway to commerce between regions. The VOC relied on Teluk Betung to collect and transport the spices obtained in Lampung Province. As an economic center for a long time, it has been able to trigger regional development. Developing the manufacturing industry, tourism, and settlements with a population density of 8050/km^2.

Groundwater is the main component of clean water sources on the coast of Bandar Lampung. Overexploitation in the period 1980 - 2010, has caused degradation in coastal aquifers. Groundwater has experienced an increase in sodium and chloride, caused by the intrusion of seawater. In 2013, the distribution zone has reached a radius of 500 m from the coastline [1]. Seawater intrusion in coastal areas is a process of infiltrating saltwater from the sea into groundwater on land. In natural conditions, groundwater will flow continuously into the sea. When the balance is disturbed, the intrusion could extended to inland. The problem of groundwater contamination by seawater has become a global problem [2][3][4].

Increasing groundwater salinity on the coast of Bandar Lampung requires regular monitoring and is supported by integrated data. However, there are various problems, the research focuses on mapping aquifer layers and faults that can affect the interaction between seawater and freshwater on land. Geoelectric and gravity methods are used to obtain initial information on coastal aquifers and structures. Geoelectric mapping is often performed to delineate aquifers [5][6][7] and evaluate zones that have been exposed by seawater intrusion [8][9][10]. Meanwhile, the gravity method is quite good in interpreting the thickness of the sediment layer and the possible presence of structures [11][12][13].

2. Coastal Geology in Bandar Lampung

The geology of the coastal of Bandar Lampung is composed of the influence of sedimentation from land runoff and ocean wave circulation to produce coastal alluvial deposits (Qa). This formation has a limited distribution and forms inconsistent contacts with the Quaternary sedimentary rock formations, Young Mountain Rock Formation (Qhv) and the Lampung Formation (QTI) and Tertiary sedimentary rocks, the Campang Formation (TPOC) and the Tarahan Formation (TPOT). The geological setting of the Bandar Lampung coast and its surroundings is shown in Figure 1.

Sedimentary rock formations and volcanic products cover bedrock in the form of metamorphic rocks consisting of migmatite, schist, genes, alabaster, and quartzite, which are included in the Gunung Kasih Complex (Pzg). Gunung Kasih Complex is in pre-tertiary age, and in some places it has a relatively shallow position [14]. The Bandar Lampung region has a complex geological setting that is influenced by tectonic pressure which results in an increase in magmatic through the bedrock and forming intrusions and lenses of igneous rock. The tectonic process forms various faults in the direction of the subduction path. Various faults can act as permeable zones that allow interactions between the saline water to move extend to inland.

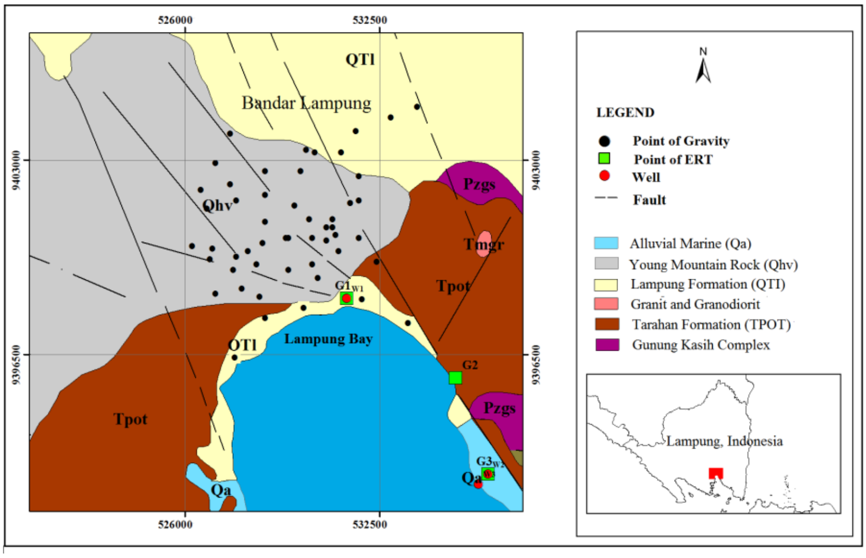

Figure 1. Geology map, well exploration, measure point of gravity, and line ERT of study area.

3. Material and Methods

There are three exploration wells in coastal alluvial deposits (Qa) with the aim of determining the constituent lithology and characterization of soil mechanics. Imaging to map the conductive zone related to the presence of aquifers and the distribution of seawater intrusion is carried out through 3 lines of electrical resistivity tomography (ERT). Measurements using the ARES instrument, with the Wenner-Schlumberger configuration, electrode spacing 6 m. As for the mapping of the thickness of the alluvial coastal sediment layer, other sediment formations and faults were analyzed through gravity measurements. Measurements using a LaCoste and Romberg gravity meter with points scattered randomly. Each data point from the well is represented by red dot (W), the electrical resistivity tomography (ERT) is symbolized by green rectangular (G), and the gravity measuring point is represented by a thick black dot.

4. Results and Discussions

4.1. Gravity

The anomaly Bouguer from gravity data is shown in Figure 2, the anomaly value ranges from 32 - 60 mgal. Low anomalies correlate with young formations, especially coastal alluvials in the south. There are indications of basins in coastal alluvials with anomalies ranging from 34 - 38 mgal (Figure 2).

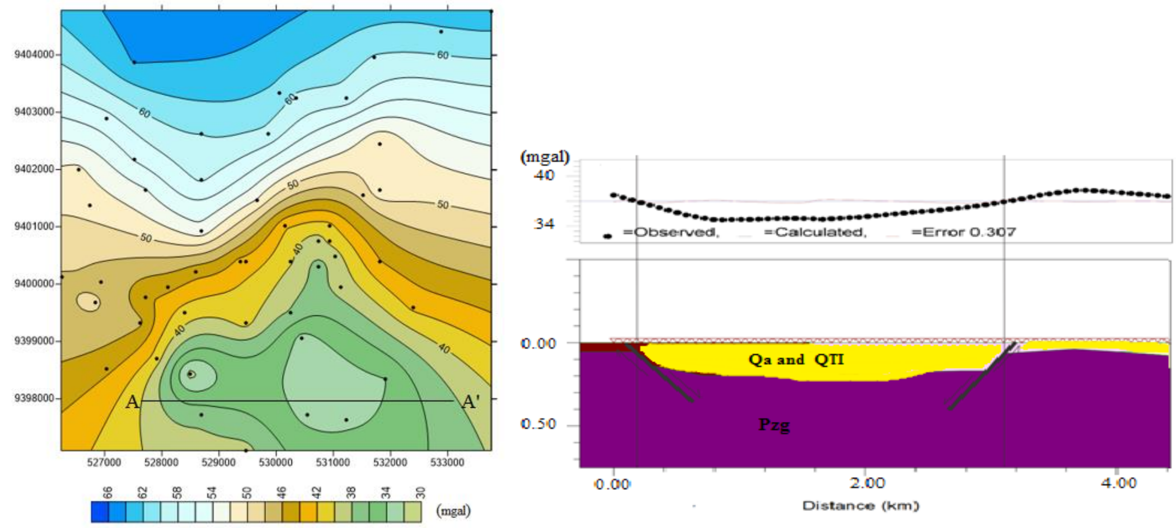

Figure 2. Map of the Bouguer anomaly with contour intervals of 2 mgal

The contour pattern of Bouger anomaly in the Lampung Bay area is in line with the existence of the fault structure in the area. The low anomaly in the south is oriented towards the northwest southeast. The direction of this anomaly is also in line with the direction of the dominant structure. To identify the effect of this structure, an incision profile was carried out on the A-A' path. Qualitative interpretation through 2.5 D modeling on slice A-A' to obtain subsurface images of the basin on the coast of Bandar Lampung. The modeling results are shown in Figure 2. The modeling results show that there are two main structures trending northwest southeast. This structure is a normal fault structure with opposite slopes to form a sag basin. This structural pattern confirms the presence of the basin from the Bouguer anomaly contour. This basin area is interpreted as a zone of potential groundwater aquifer.

4.2. Electrical Resistivity Tomography

The measurement data of three ERT lines in G-1, G-2, and G-3 is processed using Res2DInv software. The resulting image is shown in Figures 4, 5, and 6.

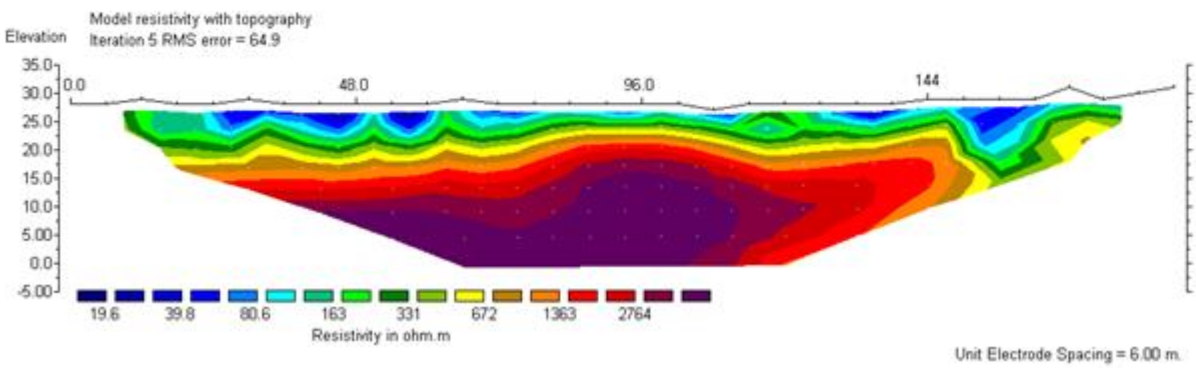

Figure 4. Inverted electrical resistivity models for Wenner-Schlumberger measurements on ERT line 1

The tomographic inversion results in Figure 4 show a low resistivity value at low depth. These results indicate that groundwater has been mixed with sea water in shallow aquifers. However, this pattern still does not show a seawater intrusion pattern, but rather a mixture of groundwater in coastal areas. This condition is reinforced by observations in the field of salt water conditions in the coastal area of Lampung Bay. The majority of residents no longer use groundwater wells and instead use clean water by buying. Meanwhile, in the port area (Panjang Port), the results of the resistivity tomography inversion also showed the same pattern as the Lampung Bay (Figure 5).

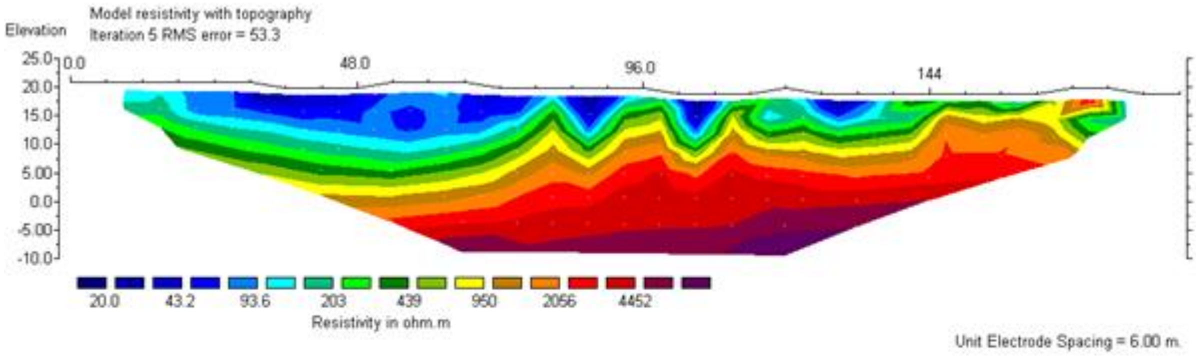

Figure 5. Inverted electrical resistivity models for Wenner-Schlumberger measurements on ERT line 2

The absence of a seawater intrusion resistivity pattern in this measurement also indicates that seawater contamination only occurs in shallow groundwater aquifers specifically in coastal areas. This condition is seen at low resistivity values with a thickness of up to 10 m at the beginning of the measurement path. The low resistivity value indicates the effect of mixed salt water on groundwater. In addition, two resistivity patterns appeared that formed a trench in the middle of the measurement path with a very low resistivity value <10 Ohm.m. This pattern is interpreted as a trench or shallow aquifer pathway which may have been formed due to the existence of the Lampung-Panjang Fault. This low resistivity pattern also indicates the presence of an accretion structure filled with saline water.

Although the ERT line 1 and line 2 measurement paths have not been able to show a seawater intrusion pattern, interesting results are shown by the third line. This route is located in the industrial area and the population, namely Srengsem Village. This area is the location for massive groundwater utilization. Several problems have emerged regarding the need for clean water in this area. The low resistivity pattern indicating the seawater intrusion zone is shown in Figure 6.

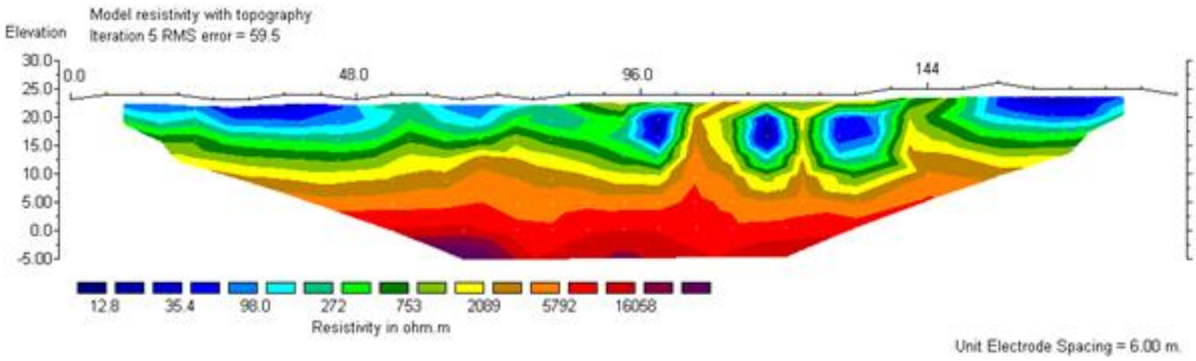

Figure 6. Inverted electrical resistivity models for Wenner-Schlumberger measurements on ERT line 3

The sea water intrusion channel that appears in the middle of the track is composed of three circular patterns. This pattern has a low resistivity value to less than 10 ohms. The path traversed by sea water is estimated to be in the geological structure gap that develops in the region. The presence of this seawater intrusion pattern can occur due to the massive use of groundwater so that the stability of the aquifer and the soil is disturbed.

4.3. Well Exploration

The constituent materials in the alluvial coastal formation produce variations in the type of lithology and thickness in the three wells. The interpretation of the drilling results is shown in Figure 7 and site class testing from the SPT compression test, the layers are still in the soft group up to a depth of 12 m in well-1, 26 m in well-2 and 32 m in well-3.

The layer in the first well (Well-1) is dominated by clay at a depth of 2 - 25 meters below sea level. Meanwhile, the sand layer with coral inserts is in the second layer with a thickness of 2 meters which is overlain by a layer of clay above it. The thickness of the clay layer in well-1 indicates an impermeable layer that holds the aquifer above it so that seawater intrusion cannot penetrate the clay layer. However, surface aquifers that are not too thick are likely to be contaminated by sea water. The density of the sand layer with coral inserts shows that the process of forming this rock layer is still influenced by the shallow marine to deep marine depositional environment.

The location of well-2 and well-3 is in the same location, namely Srengsem Village, Panjang District. Well-3 is closer to the coast than well-2. Well-3 starts with a sea water depth of up to 14 m until it meets a silt layer with an insert of coral and clay at the bottom. This indicates a depositional environment in the deep sea to shallow sea transition area. In line with well-2, the presence of a silt layer with an insertion of coral and clay at the bottom indicates a similar depositional environment in well-3. However, in well-2 there is an aquifer layer of groundwater in the form of coral sand with a thickness of approximately 6 m. This layer has the potential to act as a groundwater pathway that can be contaminated by sea water.

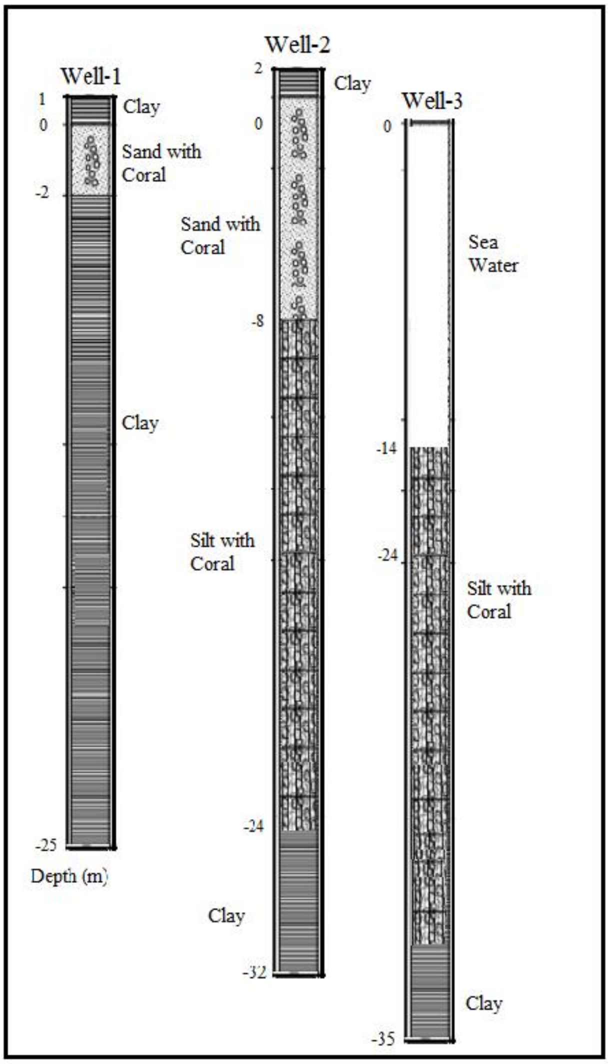

Figure 7. Litology section on three exploration well

5. Conclusions

The results of the geophysical approach to assessing the intrusion zone of seawater in the Bandar Lampung coastal aquifer have shown a mixed pattern of groundwater and seawater. The gravity method has succeeded in identifying the basin area of the groundwater aquifer in Lampung Bay controlled by the presence of two normal fault structures. One of the three ERT measurement paths successfully detected a seawater intrusion pattern in the Srengsem Village area, namely the ERT line 3. The resistivity value is quite low (<10 ohms) appears in the three circular patterns and is interpreted as a sea water intrusion zone. This finding is also reinforced from drill data, especially in well-2 which shows the groundwater aquifer layer is in a sand layer with coral inserts.

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