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 IC-STAR 2020 IOP Conf. Series: Materials Science and Engineering 1173 (2021) 012007 IOP Publishing doi:10.1088/1757-899X/1173/1/012007 1 Geophysical approach for assessment of seawater intrusion in the coastal aquifer of Bandar Lampung, Indonesia Rustadi1,2,*, I G B Darmawan2, N Haerudin2, Suharno2, and A Setiawan 1 1 Department of Environtment Science, Universitas Lampung, Jalan Prof. Soemantri Brojonegoro No.1, Bandar Lampung 35145, Indonesia 2 Department of Geophysical Engineering, Universitas Lampung, Jalan Prof. Soemantri Brojonegoro No.1, Bandar Lampung 35145, Indonesia *Email: rustadi_2007@yahoo.com Abstract. Overexploitation in 1980-2000 caused a lot of groundwater loss in the aquifer coastal of Bandar Lampung. Groundwater has been degraded with increasing salinity due to the intrusion of seawater. In 2013, the intrusion extended 400 m from the coastline. Subsurface geological mapping is carried out to examine alluvial formation's material constituents and the ability to transfer seawater to land. Three well explorations combined with three geoelectric tomography and 51 points of gravity. The gravity method is used to map structures that can connect coastal aquifers and

land aquifers. Meanwhile, 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 northwestsoutheast trending structure that can channel seawater to land aquifers. Keywords: Coastal aquifer, seawater 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/km2. The main component of clean water sources on the coast of Bandar Lampung is groundwater. Overexploitation in 1980 - 2010 has caused degradation in coastal aquifers and increased sodium and chloride, caused by seawater's intrusion. In 2013, the distribution zone 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 be extended inland. The problem of groundwater contamination by seawater has become a global problem [2-4].

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Increasing groundwater salinity on the coast of Bandar Lampung requires regular monitoring and is supported by integrated data. However, there are various problems, and 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 [5] and structures [6]. Geoelectric mapping is often performed to delineate aquifers [7-9] and evaluate zones that have been exposed by seawater intrusion [10-12]. Meanwhile, the gravity method is quite useful in interpreting the thickness of the sediment layer and the possible presence of structures [1315]. 2. Coastal geology in Bandar Lampung The geology of the coastal of Bandar Lampung is composed 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 [16]. 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 to extend inland.   Figure 1. Geology map, well exploration, measure point of gravity, and line ERT 5of the study area. 3. Materials and methods There are three exploration wells in coastal alluvial deposits (Qa) intending to determine soil mechanics' constituent lithology and characterization. Imaging to map the conductive zone related to aquifers' presence and seawater intrusion distribution is carried out through 3 lines of electrical resistivity tomography (ERT). Measurements using the ARES instrument, with the WennerSchlumberger configuration, electrode spacing 6 m. Other sediment formations and faults were IC-STAR 2020 IOP Conf. Series: 1Materials Science and Engineering 1173 (2021) 012007 IOP Publishing doi:10.1088/1757-899X/1173/1/012007 3 analyzed through gravity measurements to map the alluvial coastal sediment layer's thickness. Measurements 7using a LaCoste and Romberg gravity meter with points scattered randomly. Each data point from the well is represented by a red dot (W), the 4electrical resistivity tomography

(ERT) is symbolized by green rectangular (G), and a thick black dot represents the gravity measuring point. 4. Results and discussions 4.1. Gravity The anomaly Bouguer from gravity data is shown in Figure 2, and 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, as shown on Fig. 2. Figure 2. Map of the Bouguer anomaly with contour intervals of 2 mgal. IC-STAR 2020 IOP Conf. Series: 1Materials Science and Engineering 1173 (2021) 012007 IOP Publishing doi:10.1088/1757-899X/1173/1/012007 4 The contour pattern of the 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. An incision profile was carried out on the A-A' path to identify this dominant structure's effect. Qualitative interpretation through 2.5 D modelling on slice A-A' to obtain subsurface images of the basin on the coast of Bandar Lampung. The modelling results are shown in Figure 2 show that the two main structures are 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 the potential groundwater aquifer. 4.2. 4Electrical 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 3, 4, and 5. Tomographic inversion results is presented in Figure 3 show a low resistivity value at low depth. These results indicate that groundwater has been mixed with seawater 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 saltwater conditions 4in 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 resistivity tomography inversion results also showed the same pattern as the Lampung Bay (Figure 4). Figure 3. Inverted electrical resistivity models for

Wenner-Schlumberger measurements on ERT line 1. Figure 4. Inverted electrical resistivity models for Wenner-Schlumberger measurements on ERT line 2. IC-STAR 2020 IOP Conf. Series: Materials Science and Engineering 1173 (2021) 012007 IOP Publishing doi:10.1088/1757-899X/1173/1/012007 5 The absence of a seawater intrusion resistivity pattern in this measurement 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 saltwater on groundwater. Two resistivity patterns appeared that formed a trench in the middle of the measurement path with a low resistivity value <10 Ohm.m. This pattern is interpreted as a trench or shallow aquifer pathway that may have been formed due to the Lampung-Panjang Fault's existence. 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 shown a seawater intrusion pattern, exciting 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 5. Figure 5. Inverted electrical resistivity models for Wenner-Schlumberger measurements on ERT line 3. The seawater intrusion channel that appears in the middle of the track is composed of three circular patterns. This pattern has a low resistivity value 1of fewer than 10 ohms. The seawater path is estimated to be in the geological structure gap that develops in the region. This seawater intrusion pattern can occur due to the massive use of groundwater to disturb the aquifer's stability and the soil. 4.3. Well exploration The constituent materials in the coastal alluvial formation produce variations in lithology and thickness in the three wells. The drilling results' interpretation is shown in Figure 6 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 first well (Well-1) layer is dominated by clay 1at 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, overlain by a clay layer 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 seawater. The sand layer's density with coral inserts shows that the shallow marine still influences forming this rock layer to deep marine depositional environment. IC-STAR 2020 IOP Conf. Series: 1Materials Science and Engineering 1173 (2021) 012007 IOP Publishing doi:10.1088/1757-899X/1173/1/012007 6 Figure 6. Lithology section on three explorations well 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 seawater depth of up to 14 m until it meets a silt layer with coral and clay insert at the bottom. This layer indicates a depositional environment in the deep sea to the shallow sea transition area. In line with well-2, the presence of a silt layer with coral and clay insertion 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 seawater. 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 groundwater aquifer's basin area in Lampung Bay controlled by 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 relatively low (<10 ohms), 1appears in the three circular patterns, and is interpreted as a seawater 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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