ERT geoelectric application to determine the leakage direction of Embung Batur Agung, Karangwetan, Karangmojo District, Gunungkidul Regency, Indonesia

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ABSTRACT

Embung Batur Agung is a source of irrigation for residents around Embung. Depreciation of water in the reservoir occurs due to leakage from the geomembrane layer of the Embung Batur Agung. This study aims to determine the direction of leakage from the reservoir so that appropriate treatment can be carried out. This research was done using hydrogeological analysis and electrical resistivity tomography (ERT) geoelectrical measurements. ERT Geoelectrical measurement uses a dipole-dipole configuration with a spacing of 5 m and 10 m and a line length of 100 m. There are 2 lines in the southwest and southeast of the reservoir. The results of geohydrology analysis, it was found that the aquifer system around the reservoir included in the Gunungsewu aquifer system, and the dynamics of surface groundwater are controlled by faults and fractures. The results of the ERT geoelectrical measurement, there is a low anomaly which can indicate a reservoir leak at 50-60 m on line 1 which is in the southwest of the reservoir. This low anomaly has a vertical pattern as well as there is a fracture which is the cause of the reservoir leak. These low anomaly values range from 4-30 Ωm which can be interpreted as the presence of water that has conductive properties. The results of this study are expected to be used by the local government to handle the leakage of the reservoir.

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1. INTRODUCTION

Embung Batur Agung, located in Gedangrejo village, Karangmojo District, Gunungkidul Regency, Indonesia is an artificial reservoir that has become one of the tourist destinations in the Gunungkidul area [1]. This reservoir is one of 22 reservoir units built by the Ministry of Villages for Disadvantaged Regions and Transmigration and inaugurated in 2018 through the Director General of Disadvantaged Areas Development. This reservoir is expected to be a source of irrigation and water for residents so that the water can be used during the dry season. In addition, this reservoir is a tourist destination because of its very strategic location to see the sunset.

Embung Batur Agung was damaged in 2019 which is shown by the leakage of the geomembrane layer at the bottom of the reservoir [1]. This damage occurs due to the pressure of the water that fills the reservoir and the rocky and uneven bottom surface. This reservoir leak makes the water storage function not optimal. At the beginning of the dry season, the water had run out so it could not be used as a source of water for residents. One of the repair efforts is to patch the leaky part [1]. The position of the leak from the reservoir is important for optimizing repair activities.

The geoelectric method is one solution to determine the direction of this reservoir leak. The geoelectric method is one of the methods in geophysics that studies the nature of the electricity flow in the earth by injecting a direct current (DC) electric current that has a high voltage into the ground. Then this potential difference will be measured through a potential electrode [2]–[4]. This geoelectric method is also a method that is quite widely used and the results are quite good for detecting the presence of groundwater [5]–[8]. This method is also the main method of mineral exploration [9], [10]. In a study conducted by Bahagiarti [5], the geoelectric method was proven to be able to show the presence of subsurface caves filled with water, where geoelectrical measurements were carried out in karst areas. A study conducted by Zakaria and Suyanto [6], also shows that the geoelectric method can show the depth and thickness of a groundwater layer fairly deep depth, which is approximately 70 m where measurements are made in sedimentary areas. This means that the geoelectric method can be applied in various surface conditions with different lithologies of surface rocks. The result of this geoelectric method is the variation of the subsurface resistivity value along the measurement path. The cross-section of the resistivity value on the measurement path can be interpreted into rock types and water content. This study aims to determine the position and direction of the reservoir leakage using the geoelectric method by looking at the low resistivity value.

2. RESEARCH METHOD

This research was conducted to determine the leakage direction of the Embung Batur Agung using several methods which are hydrogeological analysis and electrical resistivity tomography (ERT) geoelectrical measurement method. The hydrogeological analysis is carried out in several stages, drone measurements, field investigations (geological mapping), and fracture analysis on the surface.

ERT is part of the geoelectrical method that measures electrical properties along lines and gets the imaging of the 2D lines [11]–[13]. The basic principle of the ERT geoelectric is to measure the response of the electric potential to the potential electrode due to the current that is inserted into the earth through the current electrode [14]–[16]. The purpose of the resistivity measurement is to determine the subsurface resistivity distribution from above-ground measurements. From these measurements, the actual value of resistivity can be predicted for subsurface resistivity related to variations in geological parameters such as mineral and fluid content, porosity, and degree of saturation of a rock. The acquisition used in this study used the geoelectric method of resistivity with a dipole-dipole configuration. This configuration is sensitive to lateral resistivity changes but has a shallow depth. Figure 1 shows the electrode placement of the dipole-dipole configuration.

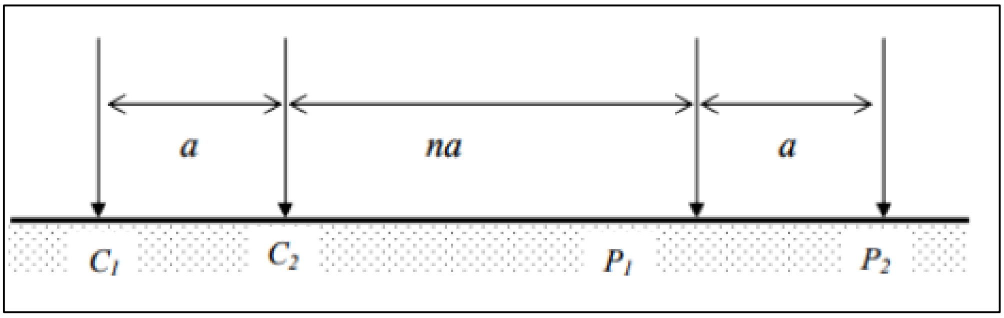


Figure 1. The electrode placement of dipole-dipole configuration [2]

Geoelectric data acquisition in this study was done along 2 lines, each with a length of 100 m. These measurement lines are designed to determine the leakage of the reservoir at a lower elevation than the reservoir, in the northwest direction of the reservoir (line 1) and southeast of the reservoir (line 2) (Figure 2). Line 1 is directed at N 150 E, and line 2 is directed at N 45 E. The configuration used in each path is a dipole-dipole configuration with varying spacing between electrodes (a) (5 and 10 m) and a multiplier factor (n) 8 (Figure 1). The penetration depth of the configuration used is around 30 m. Dipole-dipole configuration geoelectric method processing using 2D inversion of field data. The final result obtained is a cross-section of the true resistivity value.

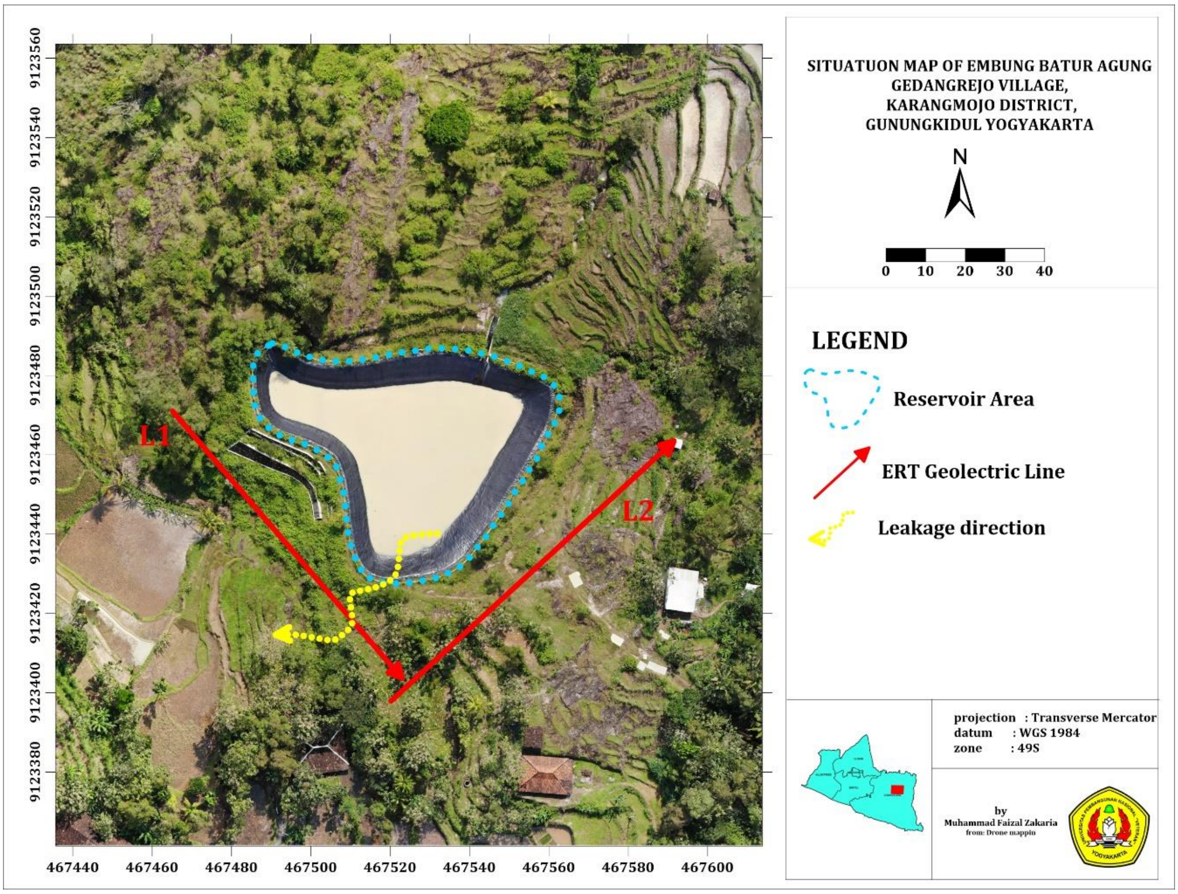


Figure 2. Embung Batur Agung situation map

According to Figure 2, the red line represents the ERT geoelectrical's line and the arrow is the direction of the lines. The area inside the blue dotted line is the Embung area. The yellow dotted line is the direction of reservoir leakage from ERT geoelectric analysis.

3. RESULTS AND DISCUSSION

3.1. Embung Batur Agung's recent condition and local geology

Embung Batur Agung is located in the village of Gedangrejo, Karangmojo District, Gunungkidul Regency, Indonesia. This reservoir can be accessed by road for 1.5 hours from downtown Yogyakarta to the east. Embung Batur Agung has been functioning as a source of irrigation for residents' agriculture since it was inaugurated in 2018, but damaged in 2019 and up to 2022 it has not been repaired. When filled, the volume of water that can be accommodated by this reservoir is around 15,000 m^3, but at this time, the remaining water volume is only around 5% of the total water volume. Reservoir damage occurred due to leakage of the geomembrane layer that forms the bottom of the reservoir to collect water. The bottom condition of the unleveled and rocky reservoir is the main problem of leakage from this waterproof membrane layer.

The leak that occurred in the Batur Agung reservoir is thought to be due to several things. This initial analysis was obtained from direct observations in the field. The initial hypothesis for the cause of the reservoir leak are; i) High water pressure on the geomembrane; ii) The bottom layer of the reservoir is uneven and not smooth (pointed and rough rocks) causing the geomembrane layer to tear; iii) The geomembrane layer is not glued at the boundary between layers. The geomembrane layer has a limited area so its installation must be done carefully. The boundary between layers usually uses overlap and is glued so that water cannot pass through the boundary between the layers. The installation of the geomembrane on the Batur Agung reservoir does not use glue so that water can pass through the gap; and iv) It is suspected that there is an active fault zone or fracture at the bottom of the reservoir, resulting in an uneven accumulation of stresses in the rock at the bottom of the reservoir which results in the tearing of the geomembrane that underlies the reservoir.

3.2. Geology of Embung Batur Agung

Generally, the geomorphology of the Karangwetan, Gedangrejo, Karangmojo District consists of hills and undulating plains, composed of volcanic rocks, with an elevation of around 880 meters above sea level. Figure 3 shows the landscape of the Karangwetan area and its surroundings, in the form of hills and undulating plains.

Figure 3. The landscape of the Karangwetan area and its surroundings

Physiographically, the Karangwetan area and its surroundings are part of the Baturagung sub-zone, the Southern Mountains zone of the western part of East Java. Van Bemmelen [17] divided the Southern Mountains into 3 sub-zones, namely the Baturagung, Panggung, Plopoh sub-zone in the north, the Wonosari Plateau in the middle, and the Gunungsewu sub-zone in the south.

Based on the regional geological map, the study area is constructed by the Semilir Formation, on which there are Nglanggran Formation, Oyo Formation, Wonosari Formation, and alluvial deposits respectively. The research area where the Baturagung Embung is located was composed of the Semilir Formation as shown in Figure 4.

3.2.1. Semilir Formation

Semilir Formation conformably overlaying above the Kebo-Butak Formation. This formation is well exposed at Mount Semilir near Baturagung, consisting of tuffaceous sandstone, lapilli tuff, tuff, sandstone, poly mixed breccia, claystone, siltstone, and shale. Repeated and alternating layering is a very typical sedimentary structure in this formation. Semilir Formation was deposited in the marine environment, during the Early Miocene age. In the Semilir Formation, especially the upper part, andesitic breccia lenses are found. There is an interfingering relationship. The thickness of the Semilir Formation is estimated at 1200 m.

3.2.2. Nglanggran Formation

Nglanggran Formation consists of volcanic breccias with andesite to basalt fragments. Sometimes tuffaceous sandstone can be found as an inserted layer. In the breccia, limestone fragments are often found, especially in the lower Nglanggran Formation. This formation was deposited in the marine environment to the terrestrial environment. The age of the Nglanggran Formation is early Miocene.

3.2.3. Oyo Formation

Oyo Formation is unconformably overlaying the Nglanggran Formation. In the Northern of the Southern Mountains area, above the Nglanggran Formation, there is a Sambipitu Formation, but in the study area, this formation is not found. The Oyo Formation consists of sandstone limestone, calcarenite, tuffaceous sandstone, and marl. Sedimentary structures that are usually found are alternating layers between calcarenite and marl. This formation is Middle Miocene in age.

3.2.4. Wonosari Formation

Wonosari Formation and Oyo Formation have a conformable relationship. Consists of bioherm limestone, reef limestone, and bedded limestone. The thickness of this formation is approximately 800 m. The Wonosari Formation was deposited in a shallow marine environment. The age of the Wonosari Formation is Miocene.

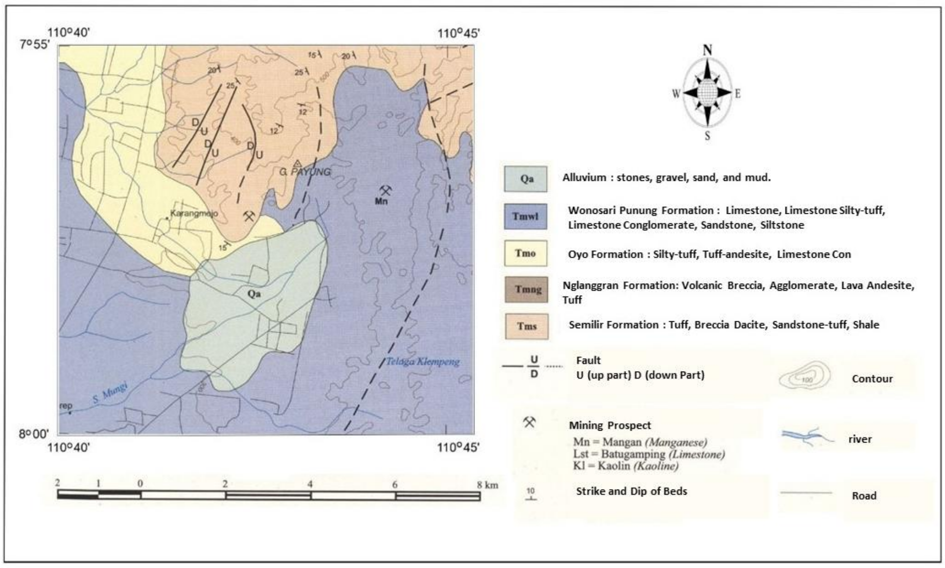


Figure 4. Geology map of Karangwetan Area [18]

3.3. Hydrogeological system of Embung Batur Agung

The hydrogeological system of the research area, and its surroundings, are included in the Gunungsewu hydrogeological system of North Gunungkidul Regency [19], [20]. The hydrogeological system in the area is built by compact volcanic sedimentary rocks, geologically belonging to the Semilir Formation. The existence and dynamics of groundwater in this area are generally controlled by geological structures, namely joints, cracks and fractures, and faults as shown in Figure 5. The movement of groundwater follows the evolving structural pattern. The shallow aquifer of the study area is assumed to be a crevice aquifer as shown in Figure 6. In the research area, the local people can dig a well or drill wells, which are generally not difficult to get water. From the field data, it was found that the depth of the dug wells ranged from 6 m to 27 m, while the depth of the drilled wells reached 100 m. Based on dug well data, it was found that in general, shallow groundwater in the study area flows relatively from the northwest to the southeast. The recharge area is in the Northwest while the discharge area is in the South.

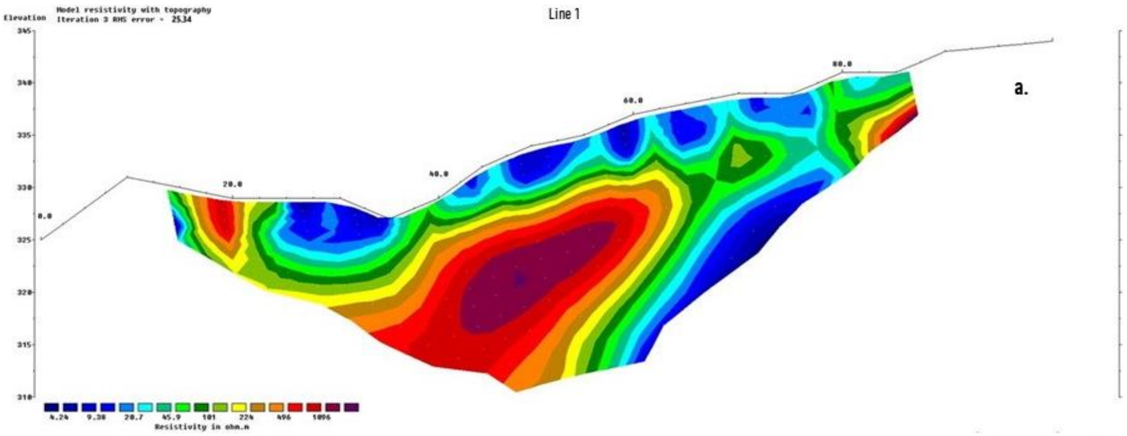
Figure 5. In Crevice aquifer, groundwater occupies and flows through cracks/fractures

Figure 6. In the Crevice aquifer, water seeps out of the rock crevices, these springs are the source of water for the Baturagung Embung

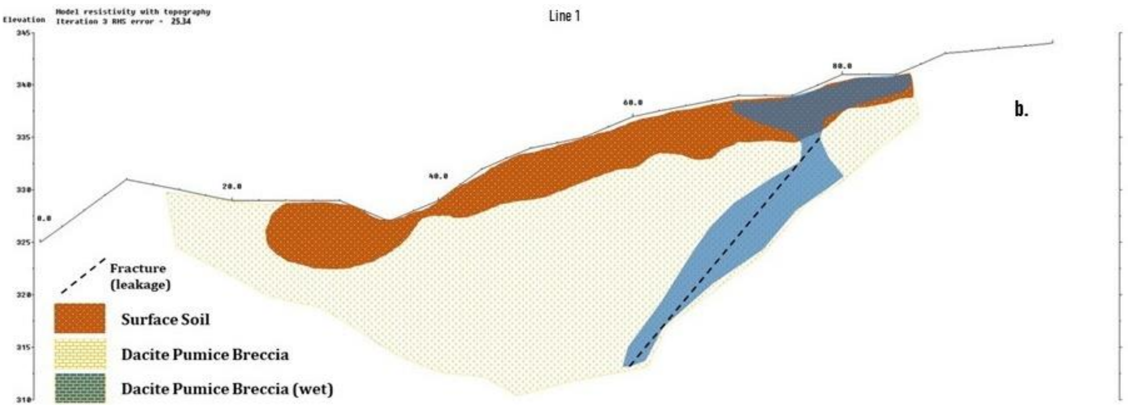
3.4. ERT geoelectric analysis

The results of the ERT method are variations in resistivity values along the measurement lines. This resistivity value will be interpreted as the type of rock and water content. In the first line, the 100 m length of measurement in the southwest part of the reservoir has the N 135 E direction. The inversion results showed variations in resistivity values between 4.24 Ωm to 1096 Ωm. Low resistivity values (4.24 Ωm to 45.9 Ωm) dominate the surface along the line. This value is the response of the surface soil in the subsurface (shown in brown color in Figure 7). The depth of this layer from the surface to a depth of 5 m. At a depth of 5 m to 30 m is dominated by high resistivity values (45.9 Ωm to 1096 Ωm). This value is the response of the Dacite pumice breccia. This Dacite pumice breccia occurs on the surface at the beginning of the lines and becomes a reference value that the high value is a Dacite pumice breccia. At the 70-80th m of the line, a low resistivity value appears (4.24 Ωm to 20.7 Ωm). This part is interpreted to be the effect of reservoir leakage. The leakage occurs because of the fractures in the Dacite pumice breccia. This fracture becomes a path of the water to the southwest of the reservoir and makes the resistivity values decrease.

The results of the inversion process on line 2, show a similar pattern (Figure 8). The surface soil on this line is thicker (from the surface up to 10 m depth) and is continued by massive Dacite pumice breccia below the surface soil layer. On line 2, massive Dacite pumice breccia with high resistivity values continue from the beginning of the track to the end of the track. There is no occurrence of low resistivity values in this path. This means that on line 2, there is no reservoir leakage which causes the Dacite pumice breccia to become wet and the resistivity value to decrease.



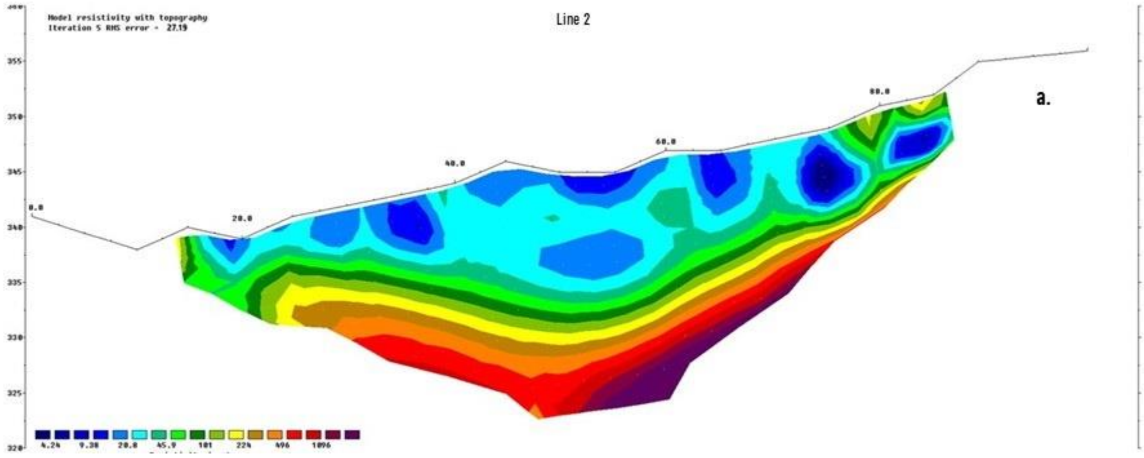
(a)



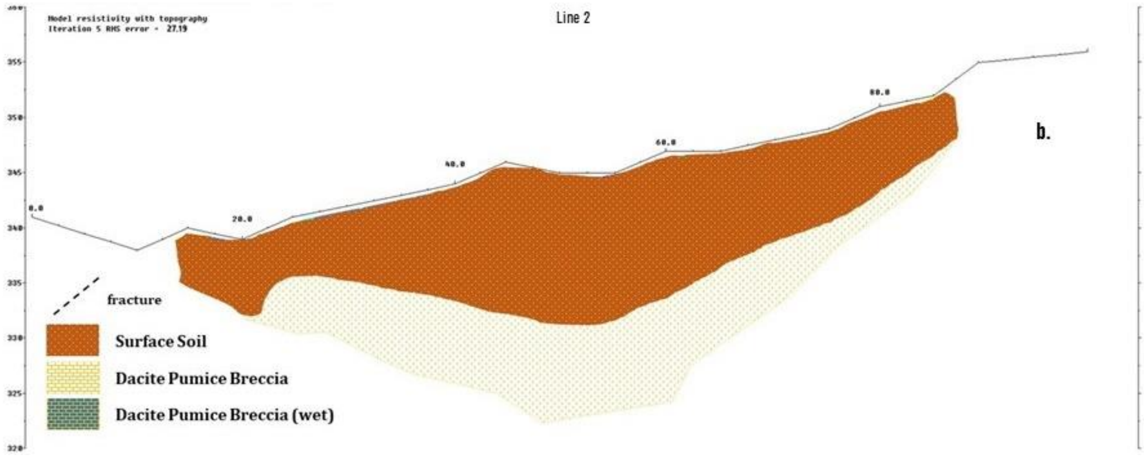
(b)

Figure 7. Interpretation of resistivity values on line 1, (a) The result of inversion of field data into actual resistivity and (b) The result of interpretation of resistivity values into rock types and water content

Based on Figure 7, there is surface soil almost along the track on the surface to a depth of 10 m. Beneath it is a massive Dacite pumice breccia. At the 80th m, there is a low resistivity value that continues up to a depth of 30 m, this value is thought to be the effect of a reservoir leak, the presence of a fracture as a passage for water and causing the Dasitan pumice breccia to be wet around the fracture.



(a)



(b)

Figure 8. Interpretation of resistivity values on Track 2 (a) the result of inversion of field data into actual resistivity and (b) the result of interpretation of resistivity values into rock types and water content

The direction of the leak is in the southwest direction of the reservoir (Figure 2). This leakage is indicated by the low resistivity value that continues to the subsurface on line 1 (Figure 7). In the southwest part of the Batur Agung reservoir, it is also a low area with a height difference of about 15 m from the reservoir. The possibility of water flowing through the fracture in the southwest part of the reservoir to a lower direction due to gravity.

4. CONCLUSION

The hydrogeological system of the research area is included in the Gunungsewu system which is built by compact volcanic sedimentary rocks (Semilir Formation). In general, the shallow groundwater flows from northwest to southeast. The ERT results show a resistivity value between 4.24 to 1096 Ωm. The subsurface is dominated by a high resistivity value as the response of Dacite pumice breccia, and there is low resistivity on the 70-80 m of the line as the response of wet Dacite pumice breccia. This part is estimated as a fracture that becomes a leakage of the reservoir. The direction of the leakage is southwest of the reservoir, and the water is estimated flowing through fracture due to the gravity effect (lower part of the reservoir).

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