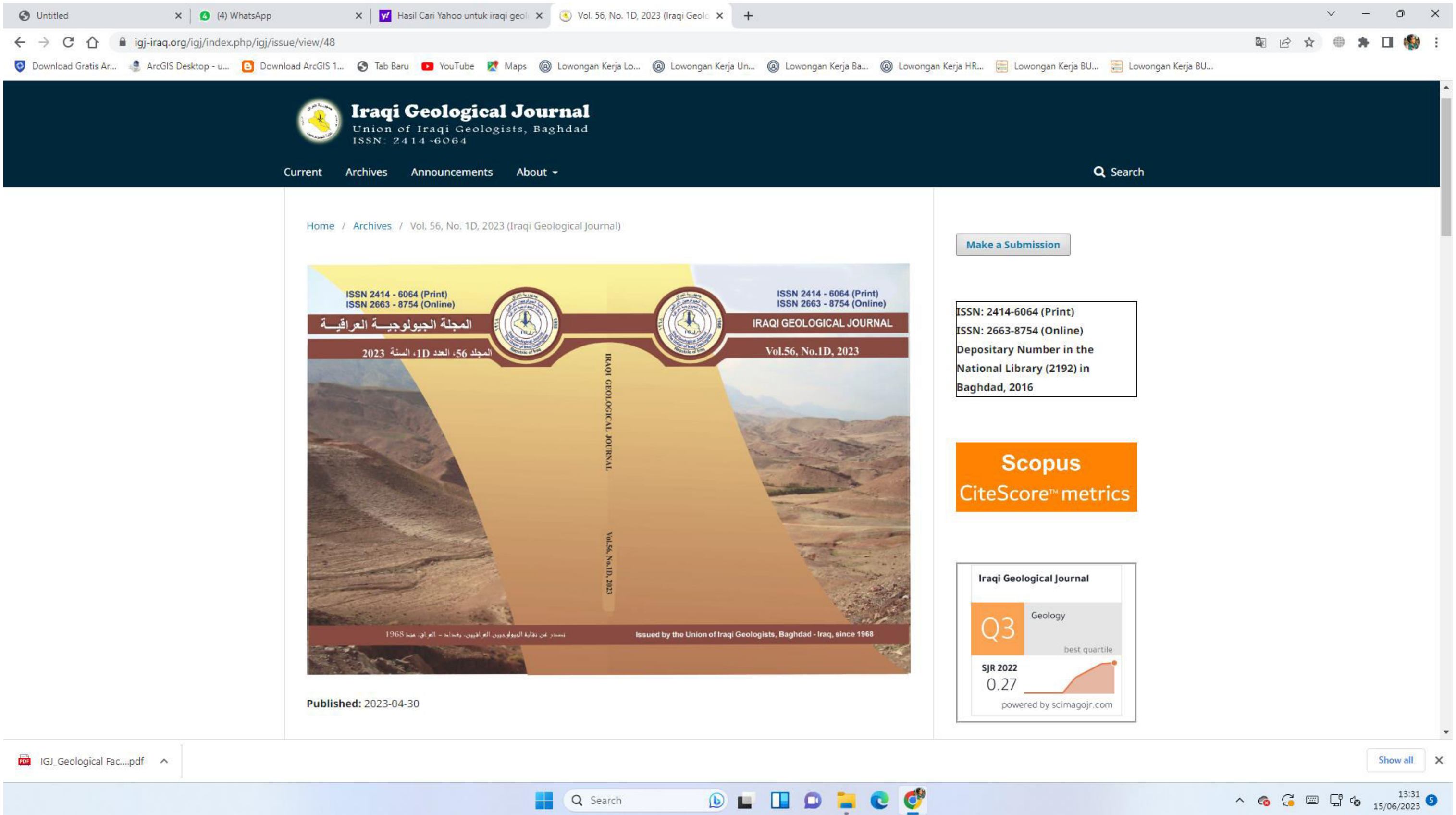
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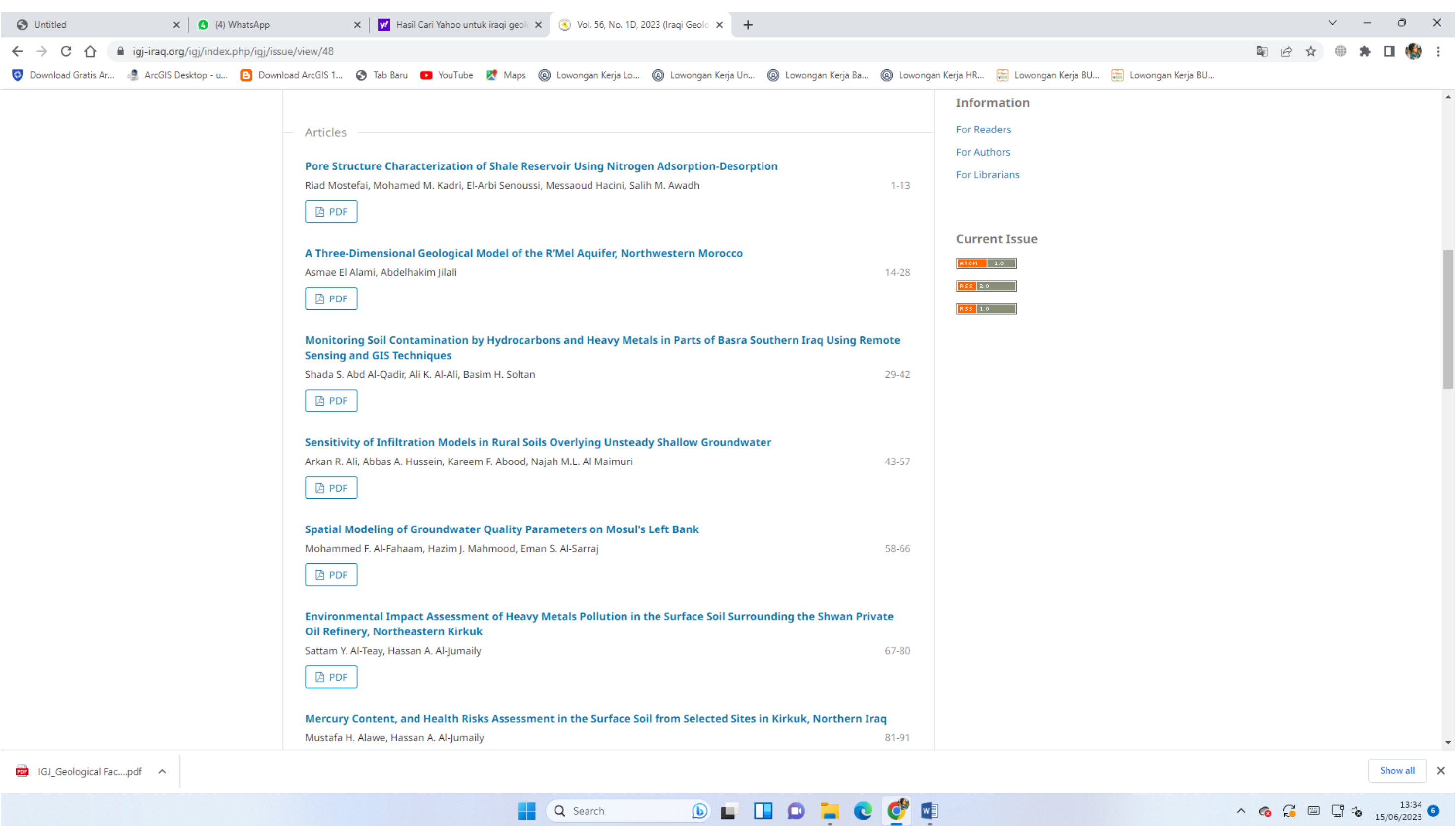
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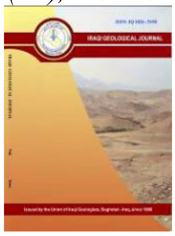

Geological Factor Causing Water Decrease of the Baturagung Reservoir, Based on ERT Geoelectric Application

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Abstract

The Baturagung reservoir, a small artificial lake is located in the Gedangrejo village, Karangmojo district, Gunungkidul regency, Yogyakarta Special Region, Indonesia. Initially, the reservoir was built on hilly geomorphology with volcanic sandstone lithology intended to meet the agricultural water needs of the people in the surrounding area, and as a tourist spot as well. Since 2019, there has been a decrease in the volume of reservoir water so that the reservoir is never fully filled with water. Due to the decrease in reservoir water volume, residents' water needs are not being met, and visitors to this place are reduced. Therefore, it is important to accomplish a study with the purpose to identify the factors that cause reservoir water depletion, such as the conditions of geomorphology, lithological variations, geological structures, and hydrogeology of the area. The methodologies used in this study are field surveys, surface mapping, and the application of the electric resistivity tomography method. The results show that there is a weak zone with a resistivity ranges 4.24– 45.9 Ωm, northeast-southwest trend, interpreted as a fault crossing the study area. It is deduced that the fault is active, causing the tearing of the geomembrane underlying the reservoir, initiating water leakage from the reservoir to the southwest direction.

Keywords: Baturagung reservoir; Fault; Geological factor; Water; Indonesia

1. Introduction

Physiographically, the study area includes the zone of the Southern Mountains, especially the subzone of the Baturagung range (Van Bemmelen, 1949; Sutarto et al, 2020). In the study area, there is a small artificial lake, called the Baturagung reservoir. It is located in the Gedangrejo village that belongs to the Gunungsewu area, which has been appointed as one of the Unesco Global Geoparks. Because of the geopark issue, almost every district in the Gunungsewu including the Gedangrejo village area likes to increase and develop its tourism potential.

The Gedangrejo village itself is known as one of the areas in the Gunungkidul regency that is subjected to water shortages, especially in the dry season (Parno, 2018). Therefore, in 2017-2018, the local government developed the Baturagung reservoir, which was initially planned to support agricultural water needs and as a tourist spot as well. However, in fact, since 2019, the reservoir has been exposed to water decrease and is suspected of having leaked at the geomembrane that underlies it, so that the reservoir's water is never full.

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As it is mentioned above, the research location is in the village area of Gedangrejo, Karangmojo district, Gunungkidul Regency, Yogyakarta Special Region, Indonesia. This area can be easily reached using motorized vehicles, both two-wheeled and four-wheeled. It is approximately 40 km from the provincial capital of Yogyakarta. Geographically/astronomically, Gedangrejo village, Karangmojo district, occupies coordinates X: 457000-468000 and Y: 91200000-9127000 on the UTM system (Universal Transversal Mercator), or110^{o}40’45”-110^{o}42’0” East Longitude and 7^{o}56’0”-7^{o}5815” South Latitude(Fig. 1.).

Now adays, the reservoir is only about half filled with water. Even in the dry season, the water loss is very significant. On the other hand, people living in the surrounding areas that predominantly work as farmers need water for their farms and rice fields (Cahyadi, 2017). Consequently, it is necessary to investigate the causes affecting the water decrease. It is hoped that the reservoir will be fully filled as expected so that it can function and be used as an agricultural water irrigation and water tourism destination according to its original purposes. Therefore, the objectives of the study are to map the geomorphology, lithological variations, and geological structures, and analyze the hydrogeological conditions in order to identify factors that cause reservoir water depletion.

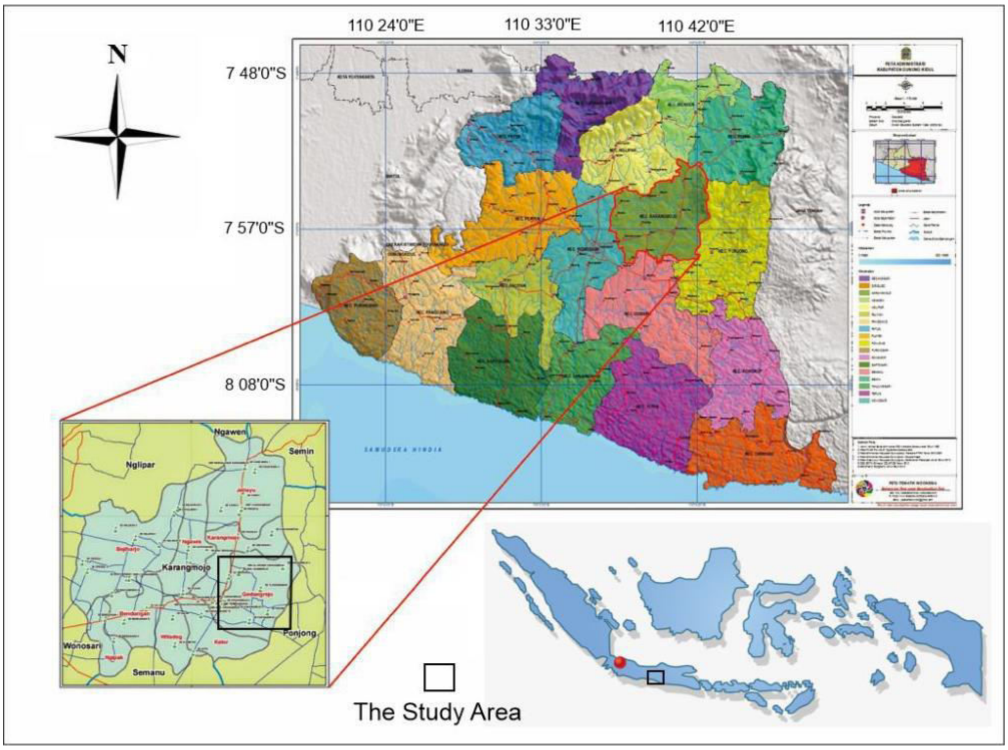

Fig. 1 Location map of the study area (BPS Gunungkidul, modified)

2. Materials and Methods

This research was carried out by applying the field survey method, geomorphological mapping, geological mapping, and hydrogeological analysis, supported by an investigation of the subsurface condition using ERT (Electrical Resistivity Tomography) geoelectric (Telford et al., 1990). Mapping the situation using drones is also carried out to provide an overview of the topography and situation of the research area (Honarmand & Shahriari, 2021).

In this study, the data used includes primary and secondary data obtained from the results of research or measurements made by other parties. The primary data sets used include measurements of the flow rate of the reservoir water supply, situation mapping, and subsurface data resulting from the application of geoelectricity (Zakaria and Suyanto, 2020). The secondary data involves regional geological maps and regional hydrogeological information.

ERT is one of the geophysical methods that measure the electrical properties of rocks along a measurement line, toa get 2-Dimensional image below the line. Basically, this method determines the response of the rock's electrical potentialagainstthe electric current that is implanted into the earth (Zakaria, 2019; Ahmad et al., 2019). From these measurements, the actual value of resistivity can be predicted for subsurface resistivity related to the variations of geological parameters such as mineral composition,porosity, fluid content, and degree of saturation of the rock (Hassan et al, 2022).The properties of rocks along themeasurement lines then can be figured intoa 2-Dimensional image.

The data acquisition was done along two measurement lines, designed to identify the subsurface condition below the reservoir location, in the northwest (line 1) and southeast directions (line 2) (Fig. 2). Line 1 is set by N150ºE direction, while line 2 is N45ºE direction. The length of line 1 and line 2 is 100 m (a = 5 and a = 10), and 75 m, (a = 5 and a = 10) respectively (Fig. 3).

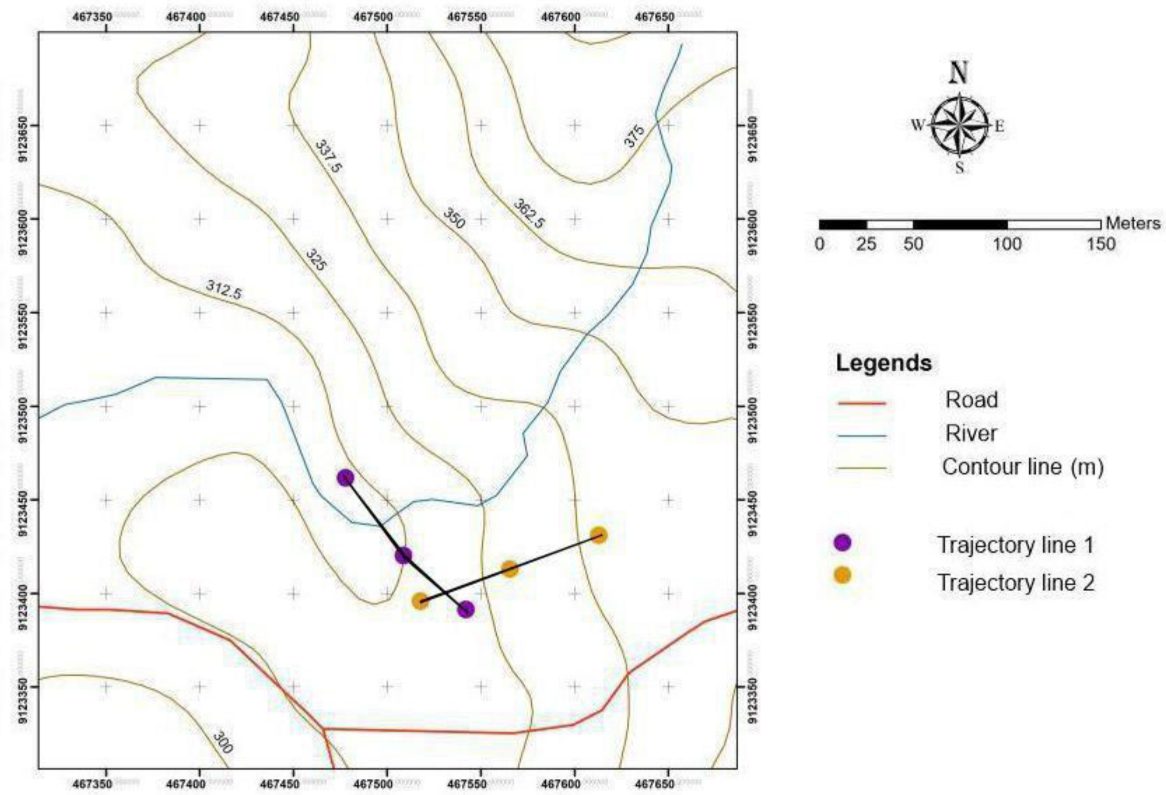

Fig. 2 Map showing the geoelectrical survey design

Dipole-dipole configuration with spacing between electrodes (a) is varying 5 and 10 meters, and a multiplier factor (n) = 8 used in these measurements for each path is (Fig. 3). This is done to get the desired penetration that rangesfrom 00-30 meters. The penetration depth of the configuration used is around 30 meters. This configuration is sensitive to lateral resistivity changes but only capable of penetrating a shallow depth (Hasan et al., 2022; Zenhom et al., 2017). Dipole-dipole configuration geoelectric method processing uses 2-D inversion of the field data. The geometry factors for the dipole-dipole configuration are:

$$k = \pi \, a \, n \, (n+1)(n+2) \quad (1)$$

The final result obtained is a cross-section of the true resistivity value.

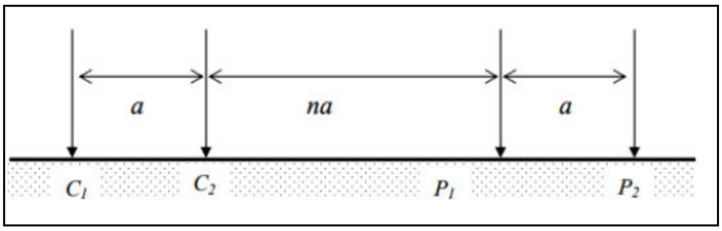

Fig. 3. Configuration of the dipole-dipole electrodes, a: electrode spacing, n: multiplier factor, C1, C2: current electrodes, P1, P2: potential electrodes (Faris et al., 2019; Williams et al., 2017)

3. Results

3.1. Geomorphology and Geology

The study area in general shows a hilly landform,and the Baturagung reservoir itself is located at an area with an elevation ranging from 312.5 m to 330 m above sea level. The situation and landscape condition of the Baturagung reservoir in the Gedangrejo village based on Google Earth images can be seen in Fig. 4.

Based on Van Zuidam classification (Van Zuidam, 1985), in general, the geomorphology of the study area can be classified into sloppy or gently inclined to undulating hills in the northern part (Fig. 5), and conical karst hills (White, 1988; Kusumayudha, 2018) in the southern and eastern parts of the study area (Fig. 5). The undulating hills are characterized by slopes ranging from 8% to 25% (5o to 15^o), dominantly occupied by tuffaceous sandstone and lapilli breccia. Conical karst hills consist of cone and dome-shaped hills with a difference in height of 30–50 m. Among the hills, there are dolines, uvala, caves, shafts, and locvas. A locva is a closed depression such as a doline or uvala that is filled with water (Kusumayudha, 2018). The conical karst hills are made of limestone, either reef or layered limestone.

Fig. 4 Landscape situation of the Baturagung reservoir and its surrounding (left), and Google Earth view of the Baturagung reservoir and its surrounding area (right).

Fig. 5. Hilly and undulating geomorphology (left), andconical hills karst topography in the study area (right)

The stratigraphy of the study area, from the oldest to the youngest consists of Semilir Formation, Oyo Formation, Wonosari Formation, and alluvial deposits, respectively. The description of each formation is as follows:

3.1.1. Semilir Formation

The Semilir Formation comprises tuffaceous sandstone, lapilli tuff, sandstone, tuff, polymixed breccia, claystone, siltstone, and shale (Fig. 6). Repeated layering is very common and is the main characteristic of this formation (Fig. 9). The Semilir Formation was deposited by a gravitational current mechanism in a deep sea environment as distal turbidity. The formation is of the Early Miocene age (Suyoto, 1994). In the Semilir Formation, andesite breccia lenses can be found. The thickness of the whole Semilir Formation is estimated to be about 1200 m (Suyoto, 1994).

Fig. 6. Tuffaceous sandstone of the Semilir Formation(left), and Repeated layering of tuffaceous sandstone, tuff, and siltstone (right)

3.1.2. Oyo Formation

The Oyo Formation is unconformable and is laid above the Nglanggran Formation. It consists of clastic limestone, calcarenite, calcareous sandstone, tuffaceous sandstone, and marl. Sedimentary structures that are usually found in the formation are alternating layers of calcarenite and marl. It was deposited in a shallow marine environment (Suyoto, 1994) (50–100 m), or from the peripheral of the neritic to the middle neritic (Suyoto, 1994). The depositional mechanism was under the influence of a rather calm wave disturbance. This formation is of the Middle Miocene geological age (Suyoto, 1994).

3.1.3. Wonosari Formation

The Wonosari Formation is conformably overlain by the Oyo Formation, and in some places, it can be shown that there is an interfingering relationship between the upper part of the Oyo Formation and the lower part of the Wonosari Formation. This rock unit consists of bioherm limestone, reef limestone, and bedded limestone (Fig. 7). The thickness of this formation is approximately 800 meters (Suyoto, 1994), while the age of the Wonosari Formation is Middle Miocene (Suyoto, 1994; Kusumayudha et al., 2022). The Wonosari Formation was deposited in a shallow marine environment, identified by the occurrence of coral fossils (Kusumayudha et al., 2021).

Fig. 7. Limestone of the Wonosari Formation: bedded limestone (left), and reef karstic limestone (right)

3.1.4. Alluvial deposits

Alluvial deposits form the youngest lithological unit in the study area. The deposits are present as the result of river sedimentation and flooding deposition in the Holocene epoch to recent times. These deposits are composed of loose material ensuing from the breakdown of the older rocks, with the grain sizes of clay, silt, sand, gravel, and boulder. Stratigraphically, the alluvial deposits have an unconformity relationship with the older rock units, such as the Wonosari Formation, the Oyo Formation, and the Semilir Formation.

Geological structures in the study area are represented by joints and faults. Rock joints, fissures, and cracks can be found everywhere. The lineament orientation of the geological structures extracted from LANDSAT is northeast-southwest and northwest-southeast (Haryono et al., 2016). There are three faults found in the study area, especially at the location where the reservoir is situated, namely Gedangrejo fault 1, Gedangrejo fault 2, and Gedangrejo fault 3. The faults strike relatively northeast–southwest (Fig. 8).

Despite the three faults, there are two other presumed faults, which can be called the GunungPayung fault and the TelagaKlempeng fault.Joints and faults are supposed to control the condition of groundwater dynamics in the study area, its distribution, and flows (Prastistho, et.al., 2017).

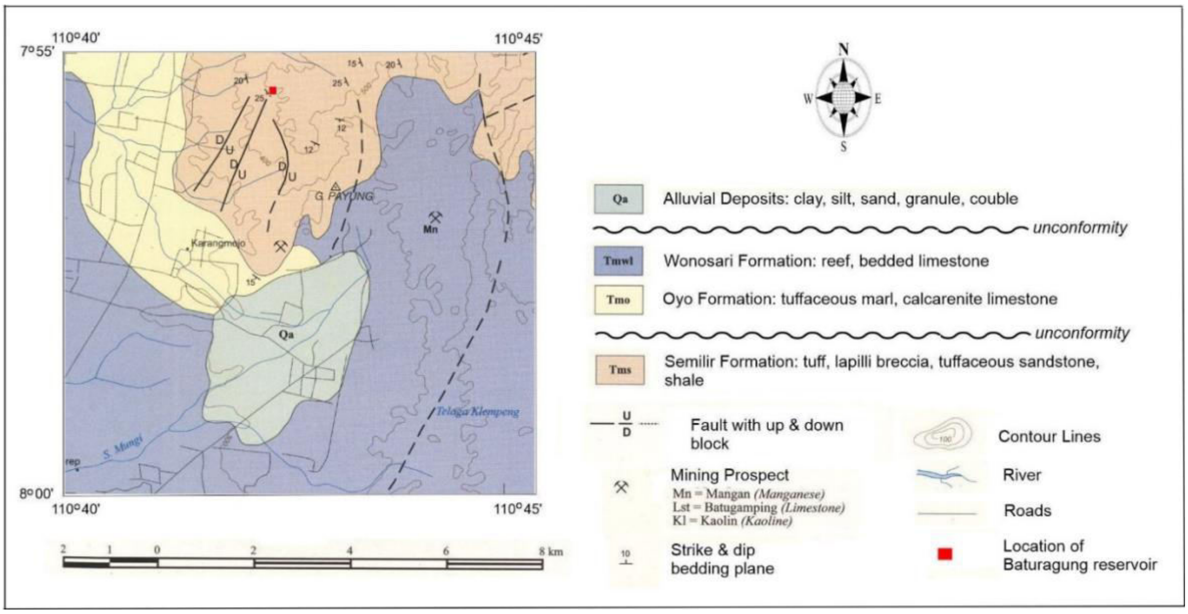

Fig. 8 Geological map of the study area, compiled from the regional geological map (Surono et al., 1992) and field mapping

3.2. Hydrogeological System

The hydrologic setting of the Gedangrejo and surrounding areas is included in the northern part of the Gunungsewu hydrogeological system (Kusumayudha, 2018). The aquifer in the area is composed of relatively compact volcanic sandstone but is highly jointed. It has undergone strong tectonic processes, indicated by the existence of joints and faults. Groundwater distribution generally follows the structural pattern that controls the dynamics of groundwater movement (Prastistho et al., 2017). The regional hydrogeological system of the study area and its surroundings, which is controlled by a series of fault systems, can be seen in Fig. 11.

Shallow aquifers in the northern part of Gunungkidul are composed of soil resulting from weathering of the bedrock. In this kind of aquifer, there are many wells dug by people to get water. From the fieldwork, it was found that the depth of the dug wells ranges from 6 meters to 27 meters, while the depth of the water table in the dug wells ranges from 1 meter to 18 meters. In other words, the water level in dug wells ranges from 150 meters to 325 meters above sea level (Prastistho et al., 2017).

Based on dug-well data, it was found that, in general, groundwater in the shallow aquifer flows from the northwest to the southeast and from the southeast to the northwest. The recharge area is in the northwest, while the discharge area is in the middle and to the south, as displayed in the hydrogeological cross section as follows (Fig. 9).

3.3. Electric Resistivity Tomography (ERT) Analysis

Results of the ERT method application show that there are variations in resistivity values along the measurement lines. The variation of resistivity values reflects the existence of different rock characteristics, including water content. At line 1, the inversion results show variations in resistivity values between 4.24 Ωm and 1096 Ωm. Low resistivity values (4.24 Ωm – 45.9 Ωm) occur near the surface along the line. (Fig. 9). The depth of this layer is from 0 to 5 meters, interpreted as a cracked weathered rock. At a depth of 5 meters to 30 meters, there are higher resistivity values (45.9 Ωm – 1096 Ωm). This value indicates the response of fresh and relatively massive volcanic (tuffaceous) sandstone. At the depth of 70-80th meter, there is a low resistivity value ranging from 4.24 Ωm to 20.7 Ωm, interpreted to be a wet crushed rock. As a result, it is assumed that the leakage occurs as a result of a fracture in the sandstone (Fig. 10).

Line 2 shows a similar pattern (Fig. 11). The jointed weathered rock on these lines is thicker (from the surface up to 10 meters depth) and is continued by massive volcanic sandstone below it. On line 2, the volcanic (tuffaceous) sandstone with high resistivity values continues 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 at line 2, there is no such weak zone (fractured) which causes the sandstone to become wet and the resistivity value to decrease (Fig. 12). A fracture or a wet soft (crushed) path is suspected to be a fault zone that acted as the cause of the reservoir leaking passageway.

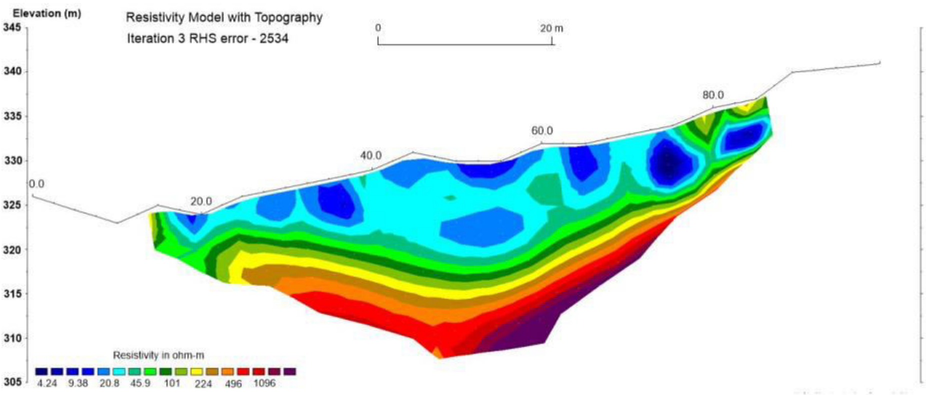

Fig. 9. Interpretation of resistivity values on line 1 (blue line, Fig.13), and the inversion from field data to the truth resistivity.

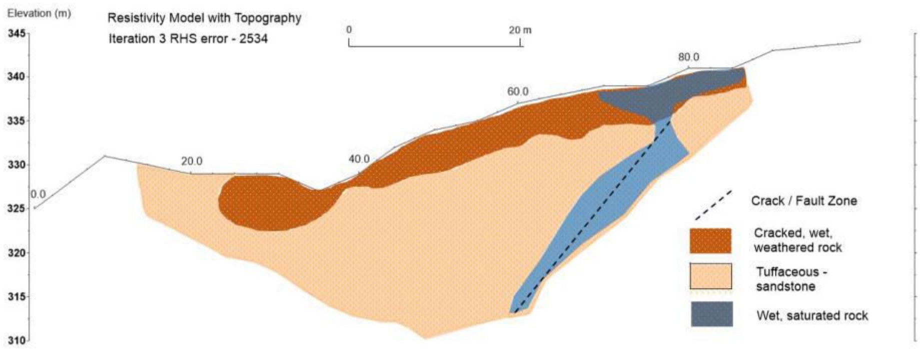

Fig. 10. The result of resistivity values interpretation into rock types and water content

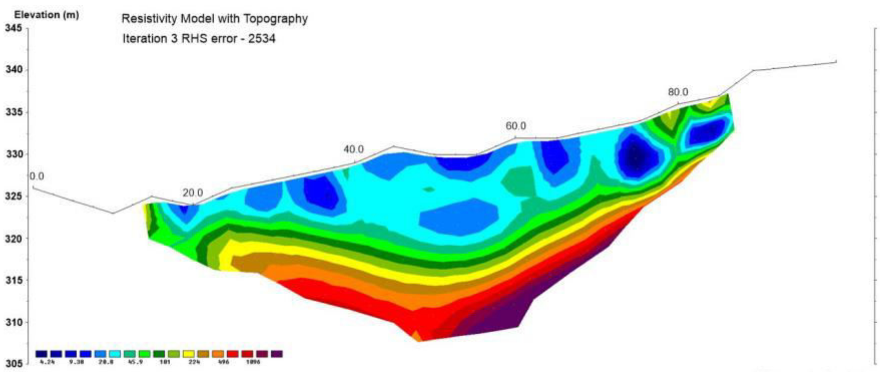

Fig. 11. Interpretation of resistivity values on line section 2 (red, Fig. 16), and the inversion from field data to the truth resistivity

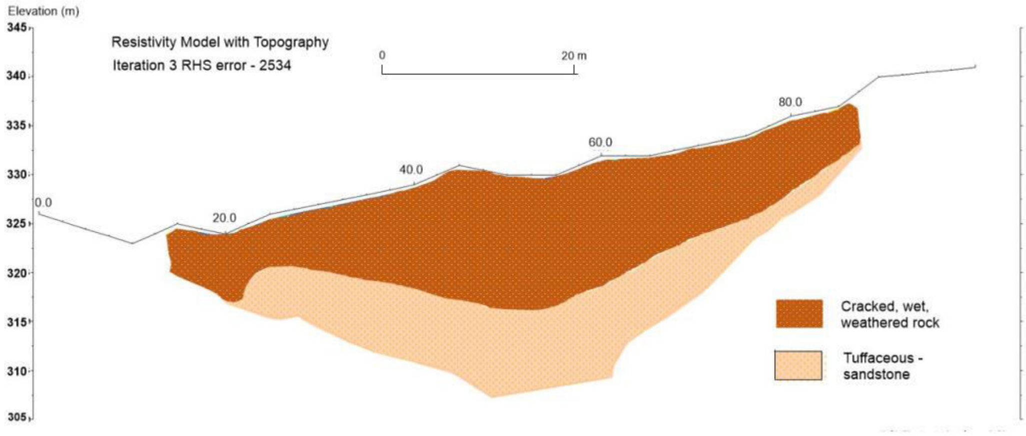

Fig. 12. The result of resistivity values interpretation into rock types and water content

Based on Figs. 9 and 12, it can be concluded that there is a path of weak or crushed rock that is wet under the reservoir. This can also indicate a leak or seepage of water from the reservoir. The seepage direction is to the southwest (Fig. 13). This weak rock path and leakage is indicated by low resistivity values (4.24 Ωm – 45.9 Ωm) that continue subsurface in section 1 (blue line).

In the southwest part of the Baturagung reservoir, there is also a low area with a height difference of about 15 meters from the reservoir. The possibility of water infiltrating through the weak path (fractures) in the southwest part of the reservoir to a lower elevation is influenced by gravity.

Referring to the geological map of the study area, it can be seen that the location of the Baturagung reservoir is in a straight line with the Gedangrejo fault 2 (Fig. 8). The existence of the fault can be proven from the results of subsurface investigations using ERT method (Figs.9 and10). In Figs. 9 to 14, a path with a low resistivity value (4.24Ωm – 45.9 Ωm, expressed in green and blue colors) can be identified, which is interpreted as the presence of a weak zone, a non-solid zone, or a wet (watery) crushing zone. This strengthens the notion that geological structures (joints and faults) control the dynamics of groundwater in the study area.

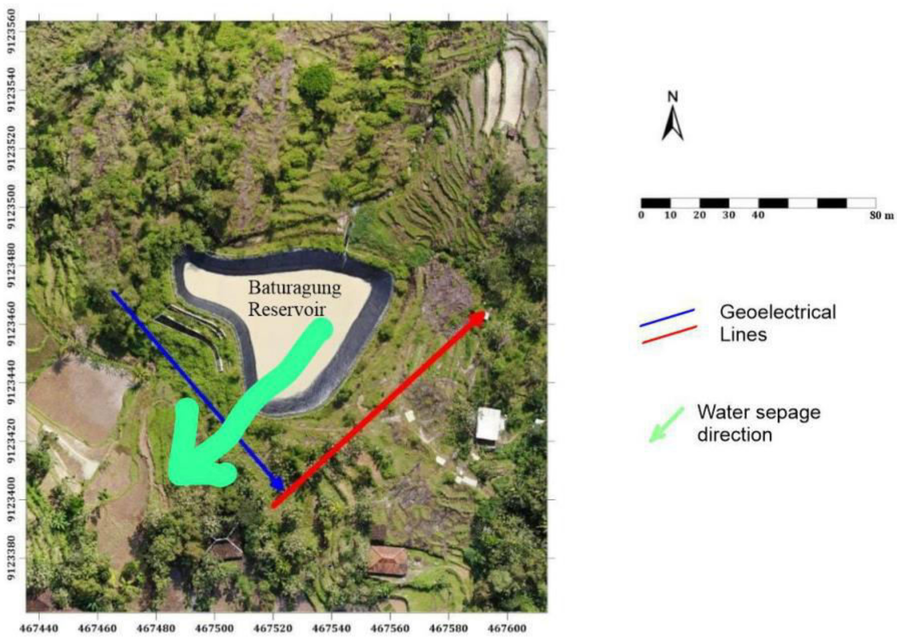

Fig. 13. Reservoir water seepage direction, based on geoelectrical resistivity analysis

In relation to the decrease in reservoir water, it is estimated that the fault that crosses the rock where the reservoir is located is an active fault. The activeness of the fault will result in uneven stress distribution and accumulation in the fault zone. It is suspected that there will be disproportionate shear stress below the reservoir, disturbing the geomembraneunderlying the reservoir, resulting in tearing, and causing the occurrence of reservoir leakage. When the reservoir water seepage flow exceeds the supply from the spring, the reservoir water volume will continue to shrink. The reservoir will only be filled again when it gets additional rainwater in the rainy season.

4. Conclusions

Based on the results, it can be concluded that the geomorphology of the Gedangrejo area and its surroundings can be classified into sloppy or gently inclined to undulating hills in the northern part, and conical karst hills in the southern and eastern parts. The undulating hills are characterized by slopes ranging from 8% to 25% (5° to 15°), while the conical karst hills consist of cone and dome-shaped hills with a difference in height of 30–50 m. Stratigraphically, the rock units, starting from the oldest to the youngest are tuffaceous sandstone, marl siltstone, and pumice breccia of the Semilir Formation, unconformably overlain by calcarenite limestone of the Oyo Formation, reef limestone, and bedded limestone of the Wonosari Formation, and alluvial deposits. There are three faults, called the Gedangrejo fault 1, fault 2, and fault 3, striking relatively northeast-southwest. The Gedangrejo fault 2 crosses the Baturagung reservoir site.

The hydrogeological system of the Baturagung reservoir location is controlled by a fissure aquifer system of jointed tuffaceous sandstone and pumice breccia. Groundwater in this aquifer occurs and moves through rock crevices with flow rates ranging from 0.4 l/sec to 10 l/sec. It can be identified that under the Baturagung reservoir, there is a wet soft/crushed rock, characterized by low resistivity, 4.24 Ωm– 45.9 Ωm, and interpreted as a wet fault zone. This fault is assumed to be active, resulting in the basement of the reservoir experiencing shear stress, eventually tearing the membrane, draining the water by leakage, and resulting in a reservoir water decrease.

5. Recommendation

A recommendation that can be put forward as a solution related to the reservoir water decrease is to do grouting with a very special formula on the fault zone under the reservoir (Supandi & Sukiyah, 2022), and monitor it regularly. In addition, it is also necessary to replace the torn membrane and find a supplementary water supply from other sources. With the addition of water supply, the water flow rate that enters the reservoir is expected to be greater than the leaked discharge, so that the volume of water in the reservoir can be maintained.

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