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IDENTIFICATION OF AQUIFER LAYERS USING THE ELECTRICAL RESISTIVITY TOMOGRAPHY (ERT) METHOD IN GUNUNG KASIH AREA

IDENTIFIKASI LAPISAN AKUIFER MENGGUNAKAN METODE ELECTRICAL RESISTIVITY TOMOGRAPHY (ERT) DI KAWASAN GUNUNG KASIH

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Abstract. The varied physiographic conditions of Lampung, from the west to the center and east, are the main factors in determining the geological field campus as a suitable learning environment. Gunung Kasih is one of the areas located on the Bukit Barisan Range, which has unique geological conditions with exposed basement rocks on the surface, making it a key factor in determining the geological field campus. However, the presence of crystalline basement rocks in Gunung Kasih prevents water from penetrating below the surface, thereby affecting the availability of groundwater for the local community. This study aims to identify aquifer layers around the Gunung Kasih area, using the Electrical Resistivity Tomography (ERT) method. Stratigraphically, based on field observations of rocks, the study area has lithology consisting of schist, marble, and sandstone in the western part, with a landscape characterised by structural hills. On the eastern side, volcanic deposits such as tuff and andesitic lava were found, with a denudational plain landscape. The geophysical survey was conducted using Wenner-Schlumberger configuration, with four survey lines oriented relatively west to east and north to south. Low resistivity anomalies are indicated by layers with resistivity values of 0–20.7 Ωm, while moderate-to-high anomalies have resistivity values of 29.9–89.9 Ωm. Very high resistivity anomalies are indicated by layers with resistivity values of 61.9–128 Ωm. In comparison with observations of rock outcrops

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and rock resistivity values, the aquifer layer is interpreted as being indicated by low resistivity anomalies in the relatively eastern part of the study area, which is near the surface to a depth of 15 metres and 25 metres. This layer is interpreted as tuffaceousrock comparable to the Hulusimpang Formation. The aquifer layer in the study area is interpreted as a shallow unconfined aquifer.

Abstrak. *Kondisi fisiografi Lampung yang beragam, dari barat hingga tengah dan timur, menjadi faktor utama penentu kampus lapangan geologi sebagai lingkungan belajar yang sesuai. Gunung Kasih merupakan salah satu wilayah yang terletak di Pegunungan Bukit Barisan, yang memiliki kondisi geologi unik dengan batuan dasar yang tersingkap di permukaan, menjadikannya faktor kunci penentu kampus lapangan geologi. Namun, keberadaan batuan dasar kristalin di Gunung Kasih menghambat penetrasi air ke bawah permukaan, sehingga memengaruhi ketersediaan air tanah bagi masyarakat setempat. Penelitian ini bertujuan untuk mengidentifikasi lapisan akuifer di sekitar wilayah Gunung Kasih, menggunakan metode Electrical Resistivity Tomography (ERT). Secara stratigrafi, berdasarkan pengamatan batuan di lapangan, daerah penelitian memiliki litologi sekis, marmer, dan batupasir di bagian barat, dengan bentang alam yang dicirikan oleh perbukitan struktural. Di sisi timur, ditemukan endapan vulkanik seperti tuf dan lava andesit, dengan bentang alam dataran denudasional. Survei geofisika dilakukan menggunakan konfigurasi Wenner-Schlumberger, dengan empat jalur survei yang berorientasi relatif barat ke timur dan utara ke selatan. Anomali resistivitas rendah ditunjukkan oleh lapisan dengan nilai resistivitas 0–20,7 Ωm, sementara anomali sedang hingga tinggi memiliki nilai resistivitas 29,9–89,9 Ωm. Anomali resistivitas sangat tinggi ditunjukkan oleh lapisan dengan nilai resistivitas 61,9–128 Ωm. Dibandingkan dengan pengamatan singkapan batuan dan nilai resistivitas batuan, lapisan akuifer diinterpretasikan terindikasi oleh anomali resistivitas rendah di bagian timur wilayah studi, yang berada di dekat permukaan hingga kedalaman 15 meter dan 25 meter. Lapisan ini diinterpretasikan sebagai batuan tufaan yang sebanding dengan Formasi Hulusimpang. Lapisan akuifer di wilayah studi diinterpretasikan sebagai akuifer dangkal tak tertekan.*

1. INTRODUCTION

Based on the physiography of Lampung, the Tanggamus area is part of the Bukit Barisan Range, which has a morphology of plains and rugged mountains (Mangga et al., 1994). Tectonically, these physiographic conditions are shaped by the Sumatra Fault, which extends from north to south across the island of Sumatra (Alviyanda et al., 2023). The undulating plains of the Bukit Barisan Range have an altitude of several tens of metres above sea level and are composed of Tertiary volcaniclastic deposits and alluvium. The area around Gunung Kasih is of interest for research due to its unique geological conditions, particularly the exposure of basement rocks at the surface. Based on the Regional Geological Map of Kotaagung (Amin et al., 1993), Pre-Tertiary rocks are exposed around Pekon Gunung Tiga, namely the Gunungkasih Complex, which consists of schist, quartzite, marble, and migmatite. The presence of Tertiary and Pre-Tertiary rock outcrops is of interest for studying the geological processes that influenced them, making this location a candidate for the Itera Geological Field Campus.

Considering the rock conditions around Gunung Tiga, which are dominated by crystalline rocks, there are interesting geological conditions related to the presence of aquifer layers. The absence of spaces that could serve as storage for subsurface fluids makes this area challenging in terms of groundwater sources. This study aims to identify aquifer layers in Pekon Gunung Tiga to assist the local community and utilise this area's potential as a Geology Field Campus with sufficient groundwater resources. The Electrical Resistivity Tomography (ERT) geophysical method is one of the techniques that can determine the distribution of rock resistivity values beneath the mountain surface, thereby identifying layers with potential as aquifers beneath the surface. The integration of surface geological and geophysical data is expected to comprehensively identify aquifer layers.

2. LITERATURE REVIEW

The island of Sumatra is composed of the combination of several terranes, namely the Sibumasu Terrane, the West Sumatra Terrane, and the Woyla Terrane. The two terranes that make up the province of Lampung are the West Sumatra Terrane and the Woyla Terrane. At the beginning of the Permian period, the Paleo-Tethys Sea narrowed as Sibumasu detached from Gondwana and moved towards the equator. The narrowing of the Paleo-Tethys Sea during the Middle Permian was accompanied by the expansion of the Meso-Tethys Sea. By the Late Permian, the Paleo-Tethys Sea was completely closed off, forming the Raub Betong Suture. During the Mesozoic era, the subduction of the Meso-Tethys Sea led to the formation of the Medial Sumatra Tectonic Zone fault. This fault caused the West Sumatra Terrane to shift from Malaya to the southwestern side of the Sibumasu Terrane. After the West Sumatra Terrane shifted, a collision occurred between the Woyla Terrane and the West Sumatra Terrane, completing the convergence of the terranes that form the island of Sumatra. The Woyla Terrane is the last continental crust to undergo collision in the formation of Sumatra Island in the Late Cretaceous (Barber, 2000; Hall, 2012; Metcalfe, 1996, 2013; Zahirovic et al., 2016). According to Barber and Crow (2009), this event resulted in the metamorphism of the Gunungkasih Complex and regional uplifting. During the Oligocene period, the subduction of the Indo-Australian Plate against the Eurasian Plate caused the formation of the Bukit Barisan Range and activated the Sumatra Fault (Barber et al., 2005; Barber et al., 2009; Muraoka et al., 2010).

Based on the Regional Geological Map of Kotaagung (Amin et al., 1993), the study area is composed of the Gunungkasih Complex (Pzg), comprising schist, quartzite, marble, and migmatite of Paleozoic age. Additionally, there is the Menanga Formation (Km), which consists of an alternation of shale, claystone, and sandstone, with intercalations of limestone and limestone lenses of Early Cretaceous age. The Tertiary rocks exposed in the study area are the Hulusimpang Formation (Tomh), consisting of volcanic breccia, lava, andesitic basal tuff, altered, quartz-veined, and sulphide-mineralised rocks of Late Oligocene-Early Miocene age. The Intrusive rocks (Tm) consist of granites, granodiorites, diorites, and dacites of Middle Miocene age. The regional geological and stratigraphic map can be seen in **Figure 1**.

Groundwater is water located in the saturated zone with an impermeable layer at the bottom and the water table at the top (Putri et al., 2022). The water table is the upper boundary of the saturated zone (Winter et al., 1998). An aquifer is a geologic formation saturated with water that has the capacity to store and release water through its natural conditions in sufficient and economically viable quantities (Darsono, 2016). Generally, aquifer layers can be divided into two types: unconfined aquifers and confined aquifers. Unconfined aquifers are bounded by one impermeable layer, while confined aquifers are bounded by two impermeable layers. In areas composed of crystalline rocks, the groundwater table tends to be closer to the surface, and topography significantly influences the elevation of the groundwater table (Winter et al., 1998).

Based on the Regional Hydrogeological Map of Kotaagung Sheet (Syamsul et al., 2009), the study area consists of two types of areas: scarce groundwater and low-productivity aquifers. The scarce groundwater area occupies the northeastern part, while the low-productivity aquifer area dominantly occupies more than 75% of the study area (**Figure 2**). Based on the Groundwater Basin Map of Lampung (Kementerian ESDM, 2022), the study area is predominantly not located in a groundwater basin area, as only 6% of the eastern part is included in the Metro-Kotabumi Groundwater Basin Area.

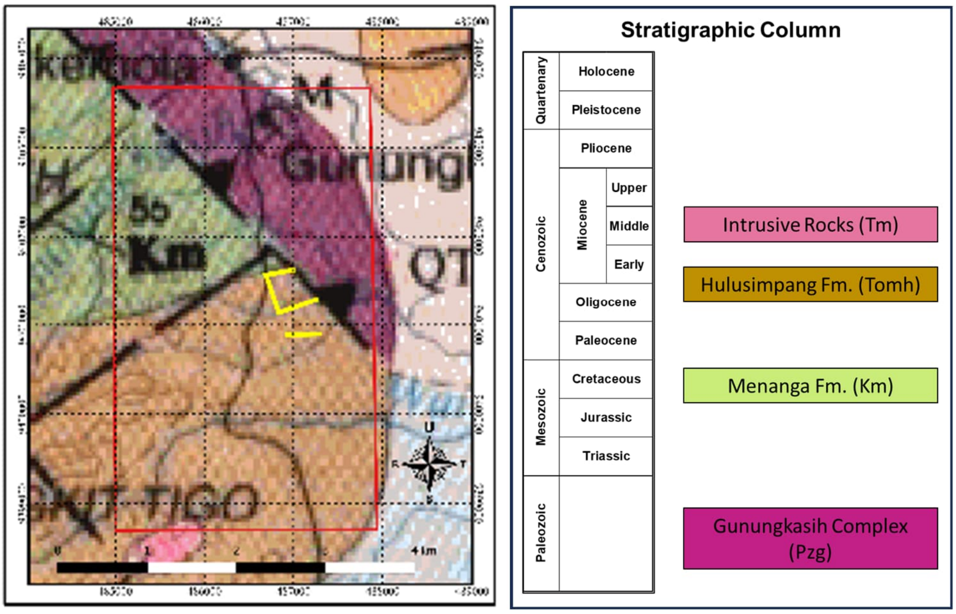


Figure 1. Regional Geological Map of Kotaagung Sheet and Stratigraphic Column (Amin et al., 1993). The red box indicates the research location and the yellow line represents the resistivity measurement.

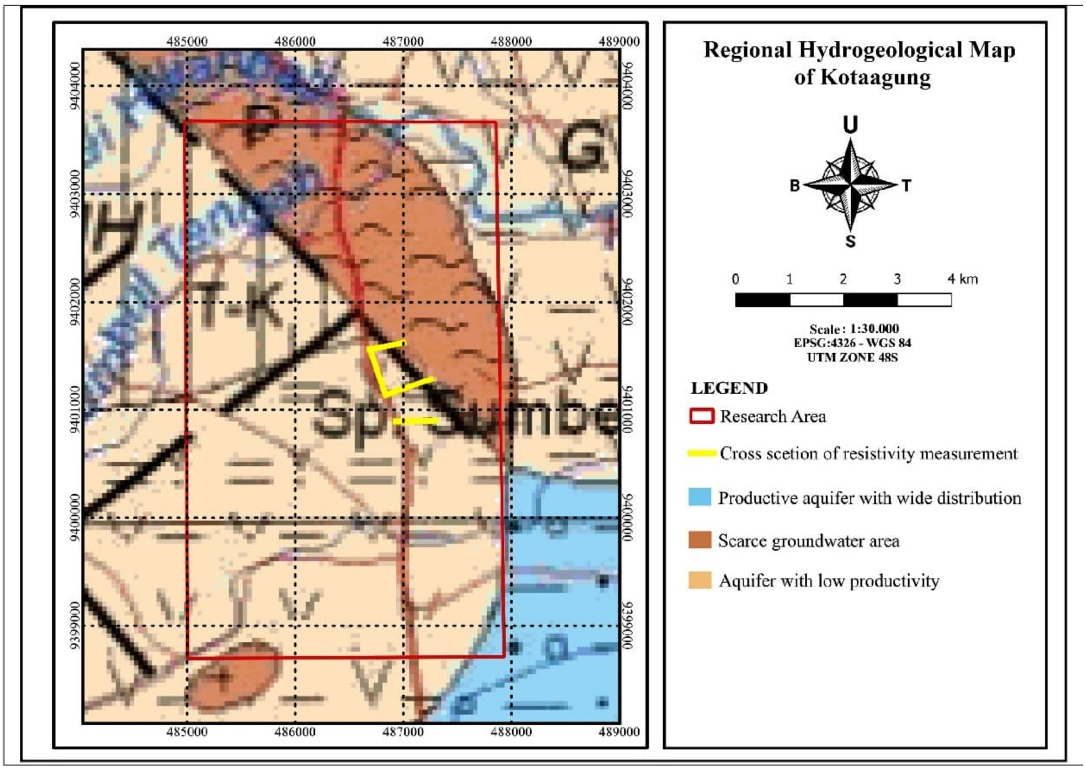


Figure 2. Hydrogeological Map of Kotaagung Sheet (Syamsul et al., 2009).

3. RESEARCH METHODS

This research was conducted using geological and geophysical methods. The geological methods used included observing rock outcrops around the research area and describing the rocks macroscopically and microscopically. Rock samples were collected to identify lithology microscopically, including mineral composition and rock structure, using a polarising microscope at the Itera Petrology Laboratory. Furthermore, a hydrogeological survey was conducted in the form of groundwater level measurements at several wells around the study area to determine the general distribution of groundwater levels in the study area (**Figure 3**).

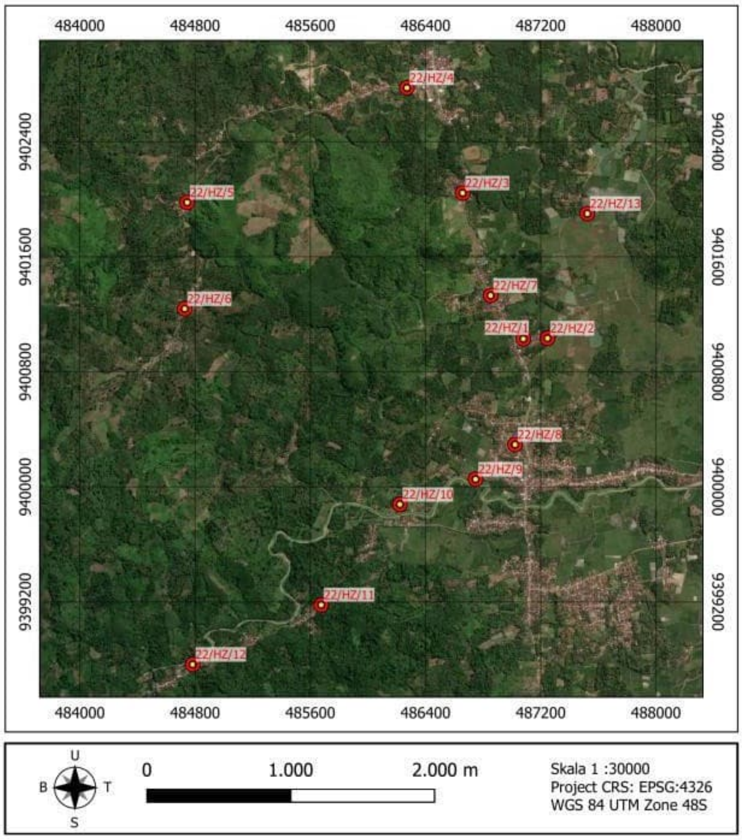


Figure 3. Map of groundwater level measurement locations.

This study used the geophysical method of Electrical Resistivity Tomography (ERT) using four cross sections around Pekon Gunung Tiga. **Figure 4** shows a map of the measurement cross sections in the field and documentation of the measurement activities carried out around Pekon Gunung Tiga. In the geophysical survey, a DC electrical current was injected using current electrodes and potential differences to obtain the resistivity values of the rocks. The principle of geophysical measurement is that the depth range depends heavily on the length of the cable; the longer the cable, the deeper the measured depth range, and vice versa. Resistivity measurements are influenced by several factors, including grain size, mineral composition, porosity, water content, and density. The geophysical measurement configuration used was the Wenner Schlumberger method with electrode spacing of 7 metres on lines 1 and 2, and 6 metres on lines 3 and 4. The advantages of 2D multichannel geophysical surveys include faster time efficiency compared to manual methods, better resolution, and ease of measurement due to the automatic switching of current and potential electrodes. ERT data processing was performed using the RES2DINV software, with the Least Square Inversion method employed. For the selection of the Forward Modelling method, the finite element method was used, with an iteration process of up to 5 repetitions. The interpretation of the rock resistivity values obtained in the data processing was analysed based on the General Rock Resistivity Values Table (Alviyanda et al., 2014), as shown in **Table 1**.

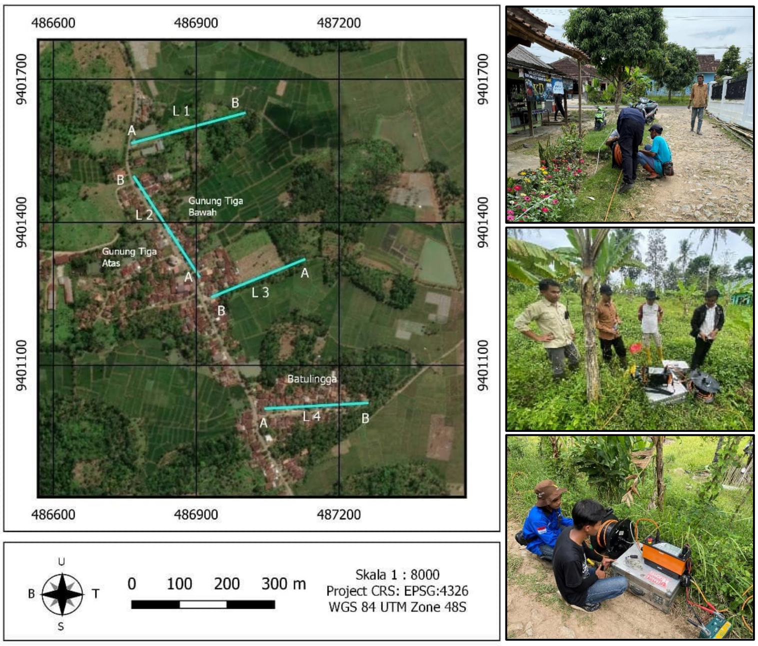
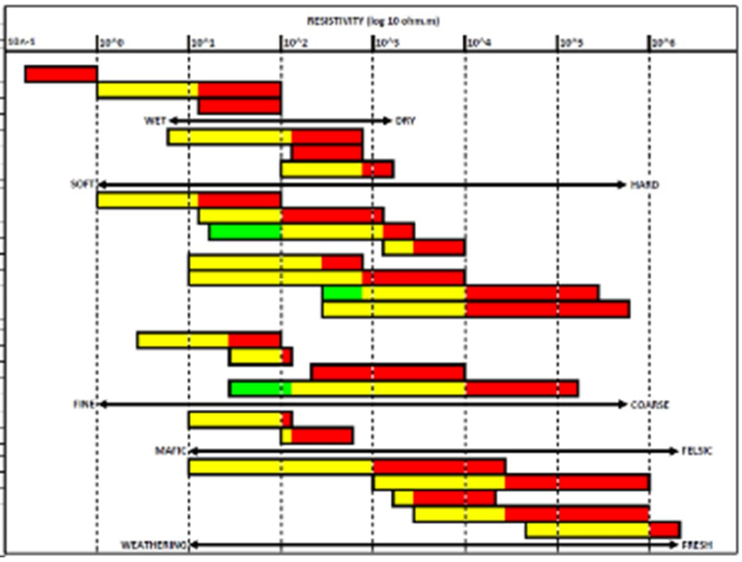


Figure 4. Map of geophysical measurement cross sections and documentation of measurement activities in the study area.

Table 1. Rock resistivity values from several literature sources (Alviyanda et al., 2014).

Material/ Rock	Description	Resistivity Value (ohm.m) min	Resistivity Value (ohm.m) max
Water	Sea Water	0.3	1
	Fresh Water	10	100
	Acid Water	20	100
Soil	Aluvium	7.5	850
	Top Soil	150	900
	Gravel	100	3,200
Sediment	Clay/Lapili	1	100
	Shale/Lapili	20	2,000
	Sandstone/Tuff	28	4,500
	Conglomerate/Aglomerate	2,000	10,000
Meta	Argilite	10	900
	Schist	10	10,000
	Slate	500	500,000
	Quarzite	500	800,000
Carbonate	Marl	5	100
	Chalk	50	150
	Dolomite	350	10,000
	Limestone	50	3.000.000
Coal	Lignite	10	200
	Coal	100	700
Igneous	Lava	100	50,000
	Basalt-Gabro	1,000	1.000.000
	Andesite-Diorite	1,000	40,000
	Ryolite-Granite	3,000	1.000.000
Meta	Gneiss	5,000	3.000.000



4. RESULTS AND DISCUSSION

4.1. Geology of the Study Area

Based on observations of rocks around the study area, at least five different types of lithology were found, namely muscovite schist, marble, sandstone, tuff, and andesite. Schist lithology is relatively widespread in the central part of the study area, characterised by weathered colours ranging from grey to light brown, foliation structure, and mica mineral lustre. The outcrops generally exhibit moderate to strong weathering. Based on petrographic observations, the minerals present include quartz (granoblastic, xenoblastic, 61.4%), muscovite (lepidoblastic, xenoblastic, 31.9%), and opaque minerals (xenoblastic, 6.7%). Overall, the observed texture is granolepidoblastic. Marble lithology is found in the northwestern part of the study area, with outcrops located in hilly areas. The rock has a fresh grey colour and a lineation structure. Based on petrographic observations, calcite minerals are granoblastic with a percentage of up to 92.8%. The outcrops and petrography of schist and marble can be seen in **Figure 5**.

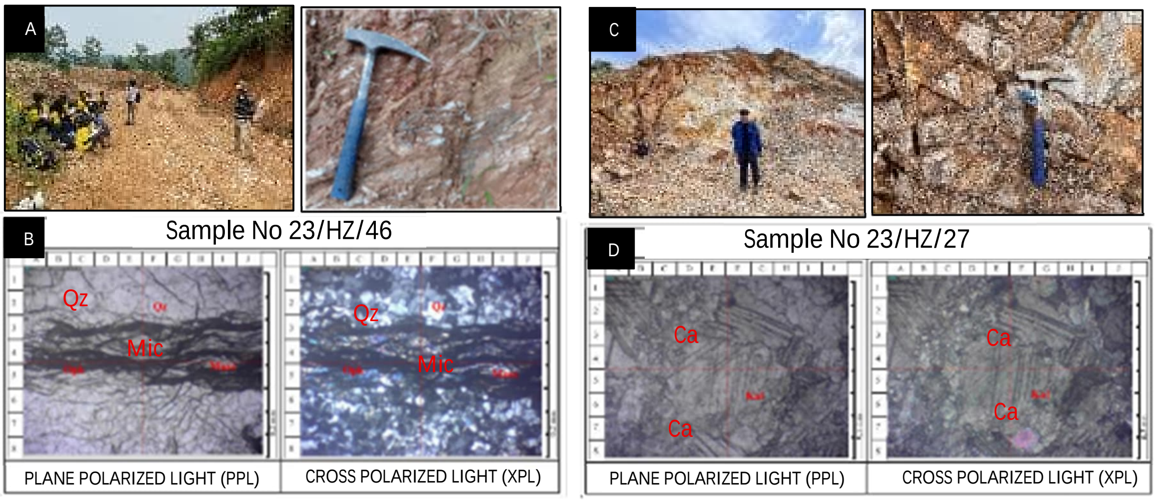


Figure 5. (A and B) Outcrops of schist rock and their petrographic appearance. (C and D) Outcrops of marble rock and their petrographic appearance. Note mineral Qz=Quartz, Plg=Plagioclase, Mic=Mica, Ca=calcite.

Tuff is distributed on the eastern side of the study area with outcrops located on hills to plains. Outcrops are generally in a state of moderate to strong weathering. Tuff have a fresh colour ranging from grey to light brown with a grain size of < 2 mm (ash). Based on petrographic observations, the rock is composed of plagioclase, quartz, opaque minerals, glass, and lithic fragments. According to Pettijohn (1975) classification, the tuff in the study area consists of lithic tuff and crystalline tuff, with a dominance of plagioclase and quartz minerals. Andesite is distributed in the southeastern part of the study area, with outcrops undergoing weathering and intense jointing. Rock samples were obtained from groundwater drilling at a depth of 6–10 m, with fresh conditions, light grey colour, and porphyritic texture. Based on petrographic observations, the minerals present are quartz (anhedral 19%), plagioclase (subhedral 78%), and opaque (3%). Based on plotting on the QAPF triangle according to the International Union of Geological Sciences (IUGS), this rock is named andesite. The outcrops and petrography of tuff and marble can be observed in **Figure 6.**

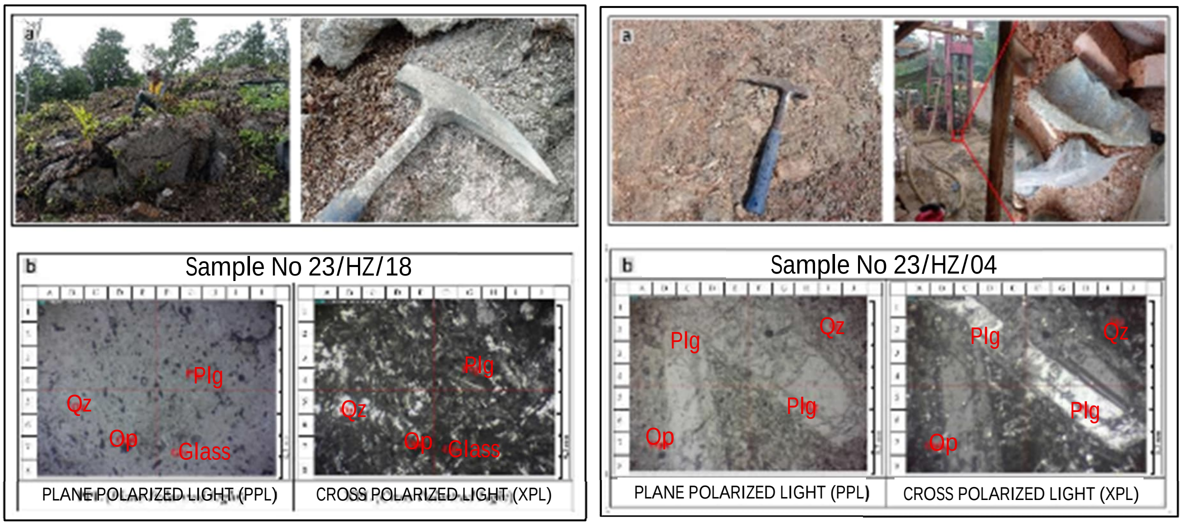


Figure 6. (A and B) Outcrops of tuff rock and petrographic rock texture of crystalline tuff, (C and D) Outcrops of porphyritic andesite rock and petrographic rock texture of andesite. Note mineral Qz=Quartz, Plg=Plagioclase, Op=Opaque.

4.2. Hydrogeology of the Study Area

Measurements at 13 well points in the study area show that the deepest groundwater level is in the western part, while the shallowest is in the eastern part, causing groundwater flow patterns to move from west to east. These groundwater flow patterns are interpreted to be influenced by the landforms and lithology of the study area. The western part of the study area has a hilly landform with crystalline rock materials, such as schist, marble, and siltstone. Meanwhile, the eastern part has a denudational plain landform with a dominance of pyroclastic rock weathering. The shallowest groundwater level is at 116 metres and the deepest is around 190 metres (**Figure 7**).

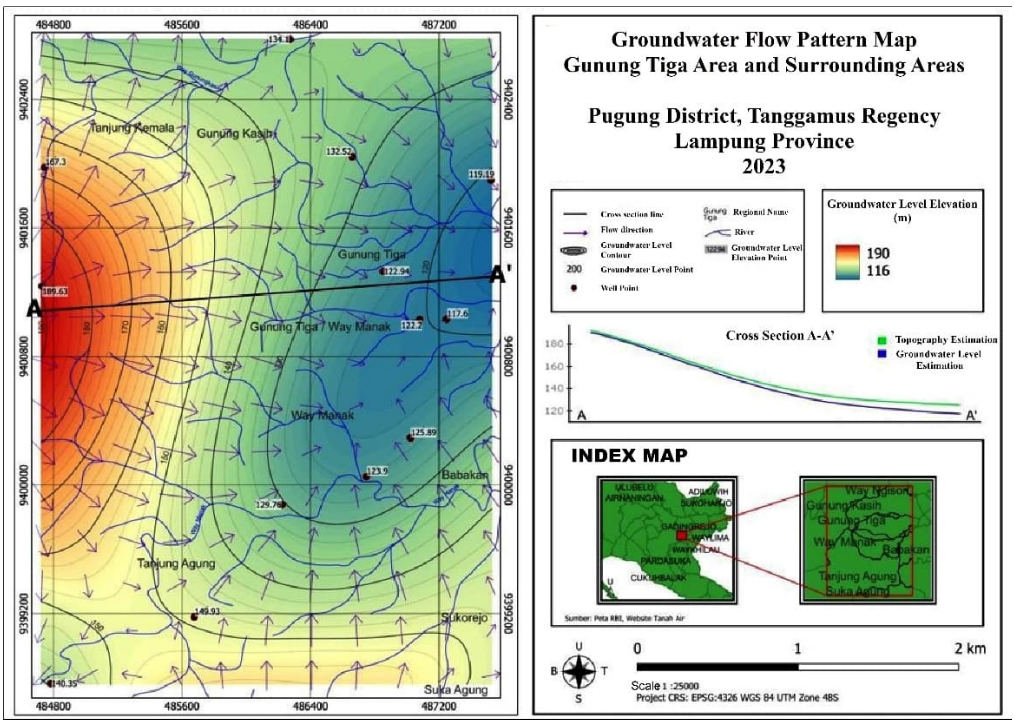


Figure 7. Groundwater flow pattern map.

4.3. Subsurface Geology of the Study Area Based on the Distribution of Rock Resistivity Values

Based on the results of geophysical measurements and data processing on four cross sections in the study area, the subsurface rock resistivity values ranged from 10 to 128 Ωm (**Figure 8**). There is a variation in resistivity values with depth, as explained below:

a. Line 1, a low resistivity anomaly is indicated by the blue-coloured layer, interpreted as the presence of fluid in the relatively western and eastern parts of the transect. Meanwhile, a moderate-to-high resistivity anomaly is indicated by yellow to brown colours. Based on the correlation of measured resistivity values with the Rock Resistivity Table (Alviyanda et al., 2014) and supported by rock observations and groundwater level measurements in the field, the low resistivity anomaly (0–20.7 Ωm) is interpreted to represent tuff rock present from the surface to a depth of 11 m. Meanwhile, the medium-high resistivity anomaly (29.9–89.2 Ωm) in the form of schist (basement) is interpreted to be present from the surface to a depth of 60 metres.
b. Line 2, low resistivity anomalies are indicated by blue layers, interpreted as the presence of fluid along the line, from north to south. Meanwhile, medium-high resistivity anomalies are indicated by green to red colours. Based on the correlation of resistivity values from measurements with the Rock Resistivity Table (Alviyanda et al., 2014) and supported by rock observations and groundwater level measurements in the field, the low resistivity anomaly (0–20.7 Ωm) is interpreted to represent tuff rock present from the surface to a depth of 25 m. Meanwhile, the medium-high resistivity anomaly (29.9–128 Ωm) in the form of schist (basement) is interpreted to be located from a depth of 25 to 60 m.
c. Line 3, which is oriented relatively east to west, there is a low resistivity anomaly indicated by the blue layer located on the the western part of the track. The low resistivity anomaly in this section is visible from the surface to a depth of 30 metres. A very high resistivity anomaly (green to red in colour) is located on the eastern side of the track from the surface to a depth of 15 metres. Based on the correlation of resistivity values from measurements with the Rock Type Resistivity Table (Alviyanda et al., 2014) and supported by rock observations and groundwater level measurements in the field, the low resistivity anomaly (0–20.7 ohm. metres) are interpreted as tuff rock, and the very high resistivity anomalies on the western surface of the track are andesite (61.9–128 Ωm). Meanwhile, the moderate-to-high resistivity anomaly (29.9–89.9 Ωm) is interpreted as schist (basement) at a depth of 25 to 50 m.
d. Line 4, which is oriented relatively west to east, low resistivity anomalies are indicated by blue layers, interpreted as the presence of fluid along most of the track. Low resistivity anomalies can be observed from the surface to a depth of 15 metres. Meanwhile, medium-high resistivity anomalies (green to red) are present from a depth of 15 to 50 m. Based on the correlation of resistivity values from measurements with the Rock Resistivity Table (Alviyanda et al., 2014) and supported by rock observations and groundwater level measurements in the field, it is interpreted that the low resistivity anomaly (0-20.7 Ωm) represents tuff rock and the medium-high resistivity anomaly (29.9 – 128 Ωm) represents schist (basement).

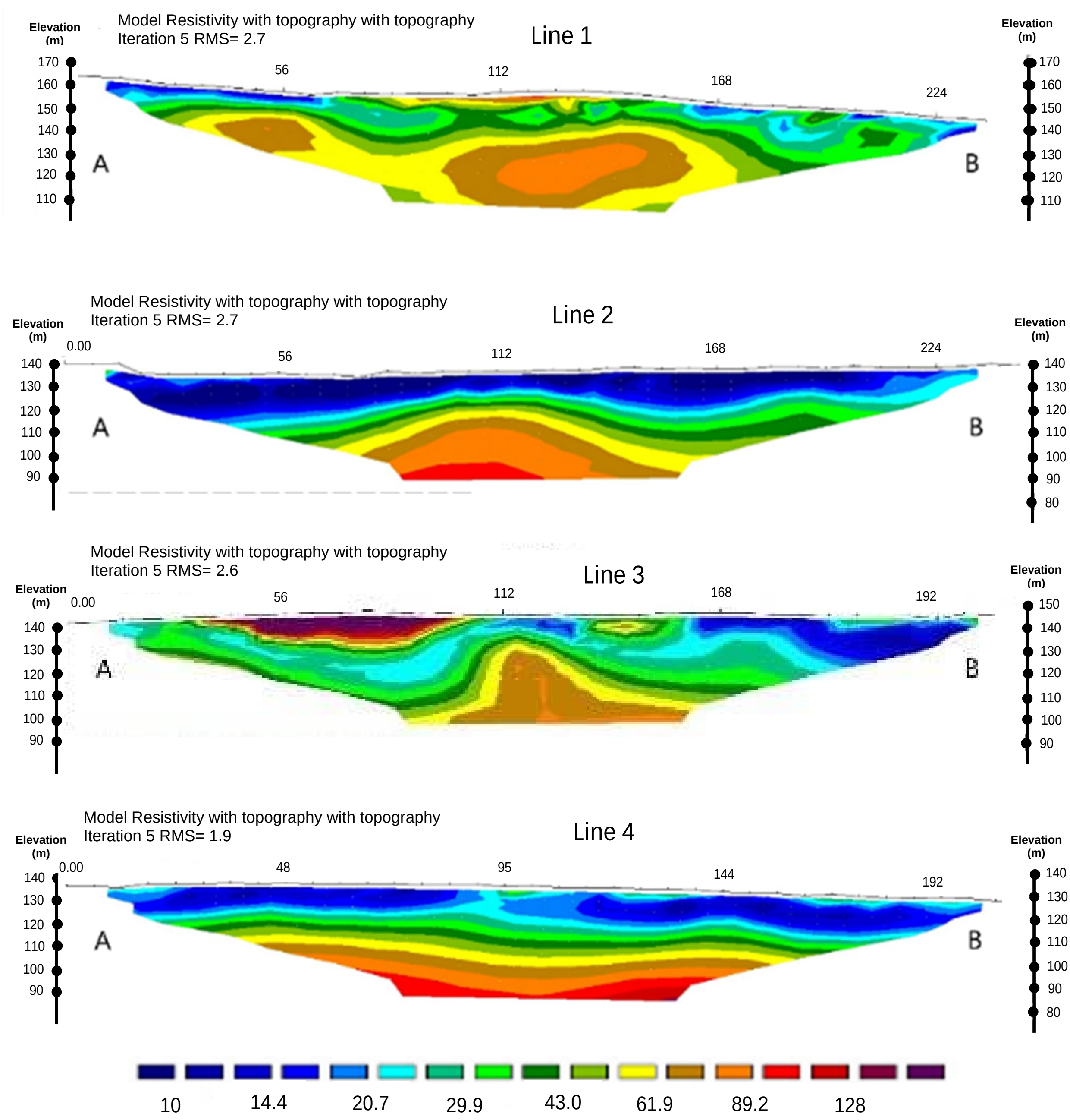


Figure 8. Model of 2D ERT geophysical measurement on four cross sections in the study area, namely Line 1, Line 2, Line 3, and Line 4.

4.4. Aquifer Layers in the Study Area

In general, based on the processing and analysis of geophysical data from the four measurement transects, the study area has relatively uniform aquifer layers in terms of aquifer depth. On Lines 2 and 4, low resistivity anomalies are observed along the transects, from the surface down to a depth of 25 m. This aquifer layer is interpreted to be composed of tuff lithology with a fine texture. Based on the regional geological map of Kota Agung Sheet (Amin et al., 1993), this lithology can be compared to the Hulusimpang Formation. This area has a denudational plain landscape with fairly intense weathering processes.

On line 1, the aquifer layer is interpreted to be distributed near the surface with an average depth of 11 m. This layer is interpreted as strongly weathered tuff with some near-surface sections flooded with water. On Line 3, a relatively massive aquifer is observed toward the relative east of the transect. The aquifer layer indicated by low resistivity anomalies is interpreted from the surface to a depth of 15 m. This layer is interpreted as weathered tuff rock. In the western part of the line, it is interpreted as andesite. This is supported by the discovery of andesite from well drilling at outcrop 23/HZ/04. Andesite has a porphyritic texture and is moderately fractured. Microscopic observations of rock samples reveal a characteristic trachytic texture in the form of lava flows, which can be compared to the Hulusimpang Formation (Amin et al., 1993).

The aquifer layer in the study area is interpreted as a shallow unconfined aquifer distributed in the eastern part of the study area. When compared with the Kotaagung Hydrogeological Map (Syamsul et al., 2009), the aquifer layer in the study area is a low-productivity aquifer.

5. CONCLUSION

The groundwater flow pattern in the study area is influenced by the topography and lithology, namely structural hills in the western to central parts with marble and schist as the constituent materials. Meanwhile, the eastern part has a denudational plain topography with tuff and andesite as the constituent materials. Groundwater in the study area flows from west to east with a groundwater level height ranging from 116 to 190 m. Based on geophysical surveys, the aquifer layer in the study area extends to a depth of 11 to 25 m. The aquifer layer in the eastern part of the study area is interpreted as a free aquifer with tuff as the constituent material, comparable to the Hulusimpang Formation.

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