Jurnal Penelitian Fisika dan Aplikasinya (JPFA)
Volume 15, Issue 2, 159-174, 2025
https://journal.unesa.ac.id/index.php/jpfa/
p-ISSN: 2087-9946
e-ISSN: 2477-1775

Study of the Existence of the Toba Pyramid Site in Marbun Toruan Village Using a Combination of Geoelectric and Satellite Imagery Methods

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Received: 10 December 2024; Revised: 20 December 2025; Accepted: 30 December 2025

Abstract

There has been research studies on the existence of the Toba Pyramid Site with the aim of finding out the subsurface rock structure. Measurements were made using ARES D4 v.47, SN: 06091345. ARES data is processed using Res2Dinv software. The results of geoelectric research show that the resistivity varies from 500 Wm to 3000 Wm estimated as alluvium, sand, gravel, dry gravel, and tuff. In addition to using Res2Dinv software, the data was also processed using surfer 13 software to obtain variations in specific gravity at depths of 5m, 10m, and 15m. In addition to using geoelectric methods, Landsat 8 OLI and USGS DEM satellite images were also used to obtain rock types at the research site. The results of the image interpretation show that the rock types of the study area are tuff and alluvium. This shows that the results of geoelectric and image interpretation are in accordance with the geological map of Marbun Toruan Village.

Keywords: *: Geoelectric; Landsat 8 OLI; DEM; Remote Sensing; Toba Pyramid Site*

How to cite: Kudadiri O, Rahmatsyah, Juliani R, Hutahaean J, Kadri M, Tampubolon T. Study of the Existence of the Toba Pyramid Site in Marbun Toruan Village Using a Combination of Geoelectric and Satellite Imagery Methods. *Jurnal Penelitian Fisika dan Aplikasinya (JPFA)*. 2025; 15(2): 159-174. DOI: https://doi.org/10.26740/jpfa.v15n1.p159-174.

INTRODUCTION

Indonesia has an exceptional cultural heritage, including temples, inscriptions, reliefs, and statues. As a cultured nation, there is ample historical evidence. One relic of the past is the temple. At some point, the temple was used as a place of worship for the gods or as a royal palace [1]. The existence of temple buildings in Indonesia demonstrates the development of Indonesian Hindu-Buddhist culture and civilization in the past [2]—a culture that spread not only in Java but also in Sumatra [3]. North Sumatra has many important but little-known relics from the past. In Humbang Hasundutan Regency, there is the Palace of King Sisingamangaraja, a historical heritage site, and

Plaosan Temple, which is very famous in Baktiraja District. Many people do not know about the temples in Sumatra because many are located far from the city. Some natural phenomena can make it challenging to investigate temples in Sumatra, such as floods, volcanic activity, and earthquakes, which can still leave temples buried underground [4]. The existence of the Toba Pyramids remains a mystery across the island of Sumatra. Therefore, government efforts are needed to dig up information about these historical relics.

On September 27, 2023, a discovery was made that people believed to be the Toba Pyramid Site. Pyramids are pyramid-shaped buildings made of large and sturdy stones. [5]. The King Sisingamangaraja Cultural Heritage Site is located in the center of the Baktiraja region, including Sisingamangaraja Palace, a replica of an ancient Batak village. This palace has great historical significance for the Batak, so it is worth telling visitors about it. [6].

Indriani Sutama and Muhammad Kadri have conducted research to identify the distribution of ancient sites in Lobu Tua Village, Andam Dewi District, Central Tapanuli Regency, using geoelectric and remote sensing methods. The results of his research show that alluvium rocks dominate the area. [7]. Rusmin also used geoelectric methods to identify archaeological objects in the Makassar sub-district. His research found ceramic objects or jars with a resistivity of 32.19 Ωm [8]. Research into the alleged existence of ancient sites has also been conducted by Rochman using geoelectric methods at the Alassumur Site in Bondowoso Regency. The results of his study identified the lithology of the constituent rocks in the research area as breccia, pasiran clay, and andesite. [9]. Sukron conducted the identification of buried archaeological objects in the Muara Jambu Temple complex using the microtremor method. [10] . The results show that the temple objects buried at a depth of 4 m are composed of alluvial rocks, including delta sediments, topsoil, mud, etc. Many studies have been conducted to obtain pairs of archaeological objects and identify the subsurface rock structure of the temple. However, research on estimating the presence of buried archaeological objects using geoelectric methods is still rare. This research will use geoelectric methods to determine the subsurface rock structure of the Toba Pyramid Site.

Based on the information above, it is necessary to conduct geophysical exploration to answer questions about undiscovered ancient sites. Remote sensing techniques provide valuable large-scale data for identifying regional geological and hydrological features. [11]. However, remote sensing applications are limited in areas where the bedrock is covered by thick regolith or vegetation, rendering the satellite imagery ineffective in revealing subsurface structures. [12]. Therefore, a combination of geoelectrical methods is required to obtain the resistivity distribution of subsurface rocks. The geoelectric method is one of the methods used to investigate subsurface structures. [13][14]. In addition, this study used Landsat 8 OLI and USGS DEM images to determine rock type. The geoelectric method is used to determine the rock type beneath the Toba Pyramid Site, and the remote sensing method is used as a supporting tool to identify rock type in the research area captured by satellite imagery. Based on this information, the author wants to conduct a study titled "Study of the Existence of the Toba Pyramid Site in Marbun Toruan Village Using a Combination of Geoelectric and Satellite Imagery Methods".

METHOD

This research uses geoelectric data, Image data (Landsat 8 OLI and Dem), and a geology map. The geoelectrical survey was conducted by employing the resistivity method to investigate subsurface rock structures. In this study, the independent variables included electrode spacing, survey line length, number of electrodes, depth of investigation, electrode positions, site elevation, injection current, and potential difference. The dependent variable was the resistivity distribution that characterizes the subsurface rock structures at the study site. Data acquisition was carried out using a series of electrodes arranged along predefined survey lines. The potential differences and injected currents were systematically recorded and later processed using the Res2Dinv software. The software was used to perform inversion, which converts field data into two-dimensional resistivity models. The inversion results were displayed as resistivity cross-sections, providing a visual representation of subsurface variations. These models served as the basis for interpreting the geological conditions of the study area.

Field data collection using the geoelectric method with Resistivity Meter ARES-G4 v4.7, SN: 0609135 [15]. Geoelectric data were collected in 3 passes, each with a track length of 75 m, using 16 electrodes spaced 5 m apart. This method can explore geothermal resources, identify rock types, rock thickness, aquifer zones, and weak soil zones. [16]. This method involves injecting an electric current into the ground, producing a voltage difference that is used to calculate the apparent resistivity at each survey point. [17]. After the apparent resistivity value is obtained, a 2-dimensional (2D) inversion model is created to interpret the anomalies in the layers below the surface of the area. [18].

Unlike direct field measurements, satellite remote sensing data acquisition does not require administrative or local authorization. [19]. Remote Sensing is the acquisition of data on Earth's surface, captured by satellites or other devices above or far from the objects. [20]. There are many types of remote sensing data produced by satellites orbiting the earth, one of which is Landsat 8 [21]. This data is used because it facilitates data collection and processing and is very effective for identifying surface spectral characteristics, given the research area's size. [22][23]. While image data is accessed through the USGS website at earthexplorer.usgs.gov [24]. The data used is the latest, dated June 23, 2023, at path: 129 and row: DEM. It is a digital model that provides surface shape information in the form of terrain. [25]. Figure 1 shows the geoelectric method and remote sensing method data grids.

Figure 1. Acquisition of geoelectrical survey lines and image data grid

Based on Figure 1, the research location is in a hilly area. The image was gridded using Google Earth. In general, the research methodology is presented in the following flowchart in Figure 2.

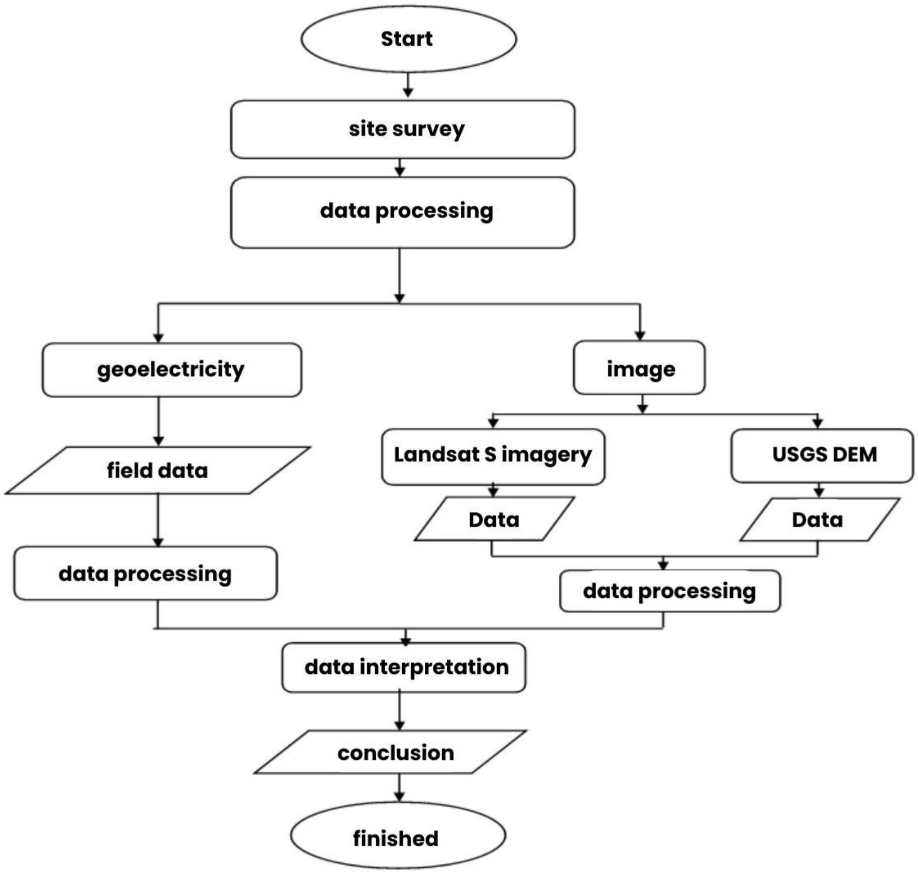

Figure 2. Research flow chart

Based on Figure 2, to obtain data interpretation, several processes are needed, from site surveys to assess the condition of the research location, to data interpretation to produce horizontal cross sections and color images. Variations in resistivity can indicate the subsurface structure in the study area.

RESULTS

A. Geoelectric

Track 1

Track 1 is located at coordinates 2°19'36.17 "N to 2°19'37.08 "N and 98°49'1.39 "E to 98°49'2.15 "E. Data were obtained using ARES geoelectric equipment, and Res2Dinv and Surfer 13 software were used to process the data. Figure 3 shows the pseudosection after the data were transformed with the Res2Dinv program.

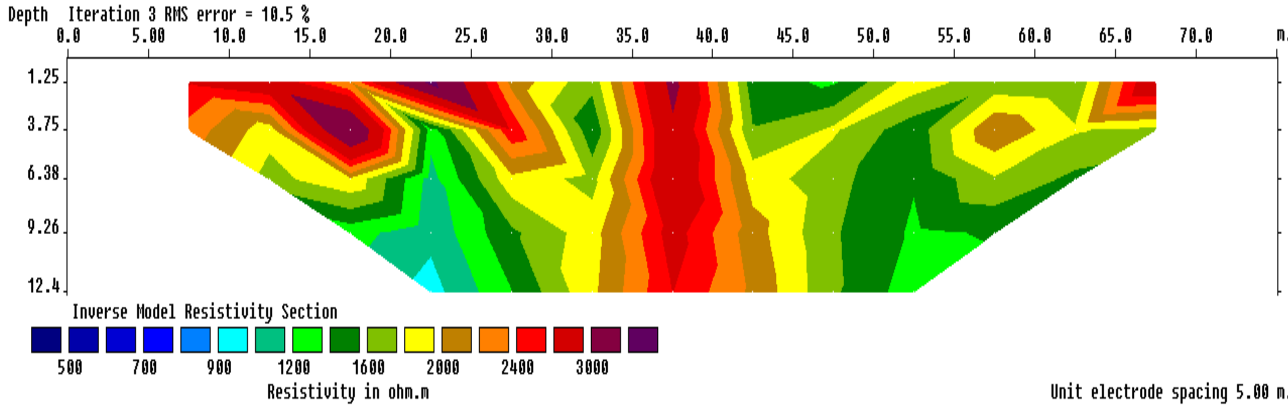

Figure 3. Pseudosection cross-section of track 1

Based on Figure 3, track 1 is identified as having 3 types of constituent rocks according to Telford. [26] and Santoso [27], table classifications described in Table 1.

Table 1. Interpretation of Track 1

Depth (m)	Resistivity (Ωm)	Interpretation
5 – 12,4	900 – 1100	Sand and dry gravel
1,25 – 12,4	1200 – 2200	Dry gravel
1,25 – 12,4	2400 – 3000	Tuff

Track 2

Track 2 is located at coordinates 2°19'36.48” N to 2°19'37.23” N and 98°49'1.16 “E to 98°49'1.81 “E. Data were obtained using ARES geoelectric equipment, and Res2Dinv and Surfer 13 software were used to process the data. Figure 4 shows the pseudosection after the data were transformed with the Res2Dinv program.

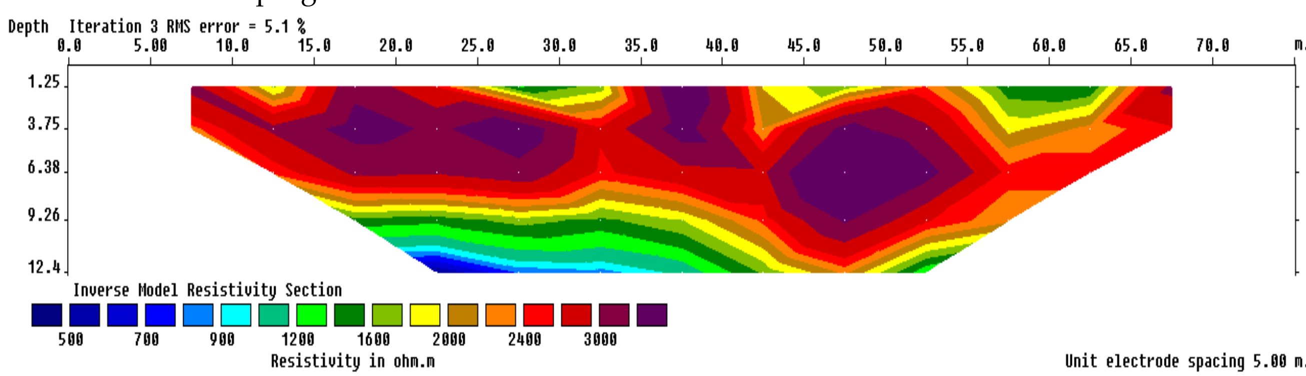

Figure 4. Pseudosection cross-section of track 2

Based on Figure 4, track 2 is identified as having 3 types of constituent rocks according to Telford. [26] and Santoso [27], table classifications described in Table 2.

Table 2. Interpretation of Track 2

Depth (m)	Resistivity(Ωm)	Interpretation
11, 2 – 12,4	500 – 1100	Alluvium, sand, and gravel
6,38 – 12,4	1200 – 2200	Dry gravel

1,25 – 12,4	2400 – 3000	Tuff

Track 3

Track 3 is located at coordinates 2°19'36.49 "N to 2°19'37.30 "N and 98°49'1.15 "E to 98°49'2.06 "E. Track 3 was obtained using 16 electrodes with a track length of 75m. Data were obtained using ARES geoelectric equipment and Res2Dinv, and Surfer 13 software was used to process the data. Figure 5 shows the pseudosection after the data were transformed with the Res2Dinv program.

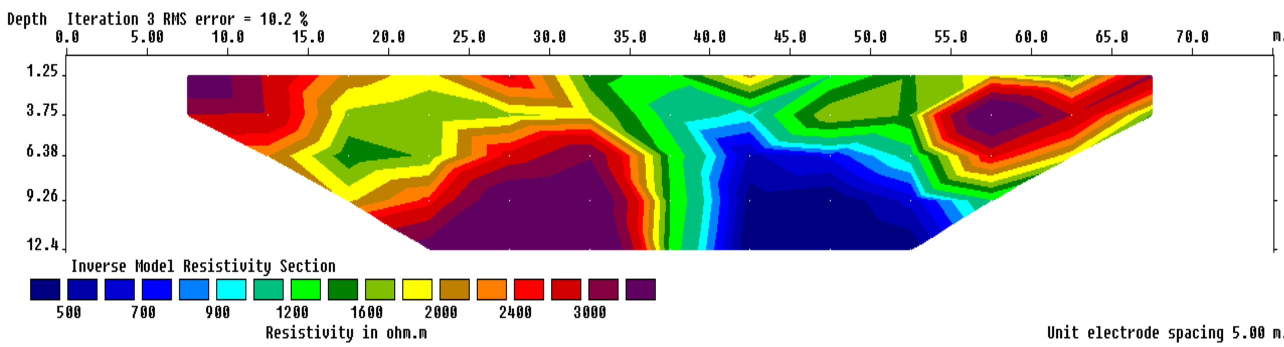

Figure 5. Pseudosection cross-section of track 3

Based on Figure 5, track 3 is identified as having 3 types of constituent rocks according to Telford. [26] and Santoso [27], table classifications described in Table 3.

Table 3. Interpretation of Track 3

Depth (m)	Resistivity (Ωm)	Interpretation
5 – 12,4	500 - 1100	Sand, gravel, and alluvium
1,25 – 12,4	1200 - 2200	sand and dry gravel
1,25 – 12,4	2400 - 3000	Tuff

The processing results using Surfer 13 software yielded merged contours for tracks 1, 2, and 3 at depths of 5m, 10m, and 15m, respectively. The results of the track contours are shown in Figure 6.

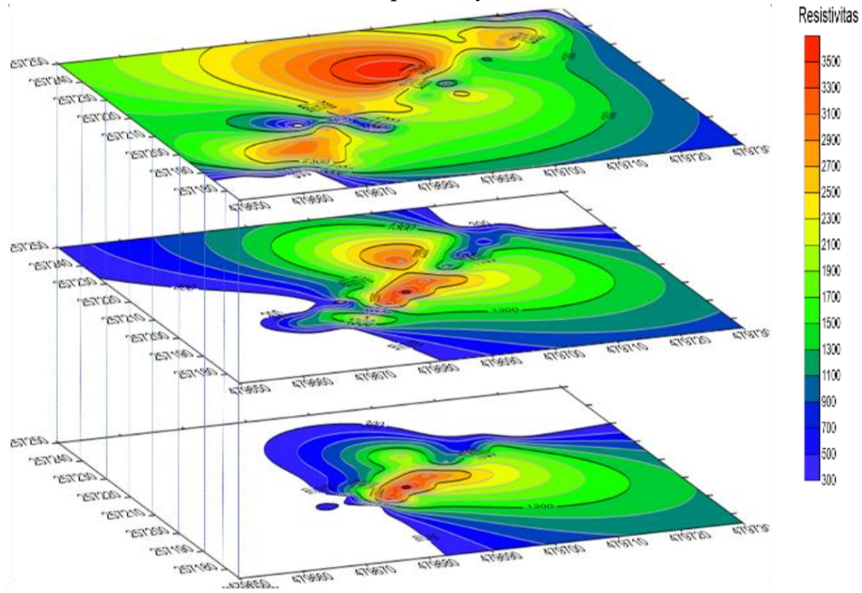

Figure 6. Resistivity contour maps at depths of 5 m, 10 m, and 15 m using *Surfer*

Figure 6 illustrates the resistivity distribution along the survey line, highlighting several anomalies at different depths. These anomalies are interpreted as tuff rock formations. Further details, including resistivity values and corresponding depths, are summarized in Table 4.

Table 4. Geoelectric table imagery

No.	Position	Depth (m)	Resistivity (Ωm)	Rock Type	Geology
1.	419660,7 - 419710,7	5	2500 - 3500	Tuff	Tufa Toba
2.	479683,5 - 479701	10	2500 - 3500		(Qvt)
3.	479683,5 - 479701	15	2500 - 3500		

As indicated in Figure 6 and Table 4, the study area is predominantly underlain by tuff rocks (Qvt). The tuff formations are distributed from 5 to 15 meters in depth, and their spatial occurrence in the study area is represented in Figure 7. Figure 7 illustrates the application of the resistivity data onto the trajectory in *Google Earth.*

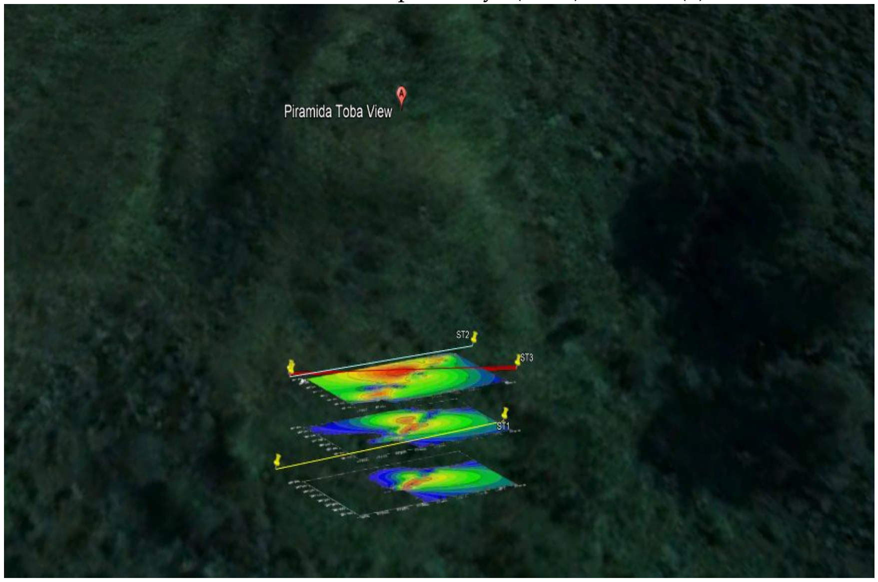

Figure 7. The resistivity models generated in Surfer were exported and applied to Google Earth to visualize subsurface variations at depths of 5–15 m

Based on Figure 7, the position of the research area is in the foothills of the Toba Pyramid Site. The acquired resistivity data were superimposed on Google Earth imagery of the Earth's surface, adjusted to their corresponding depths.

B. Remote Sensing

In addition to the geoelectric method, this research also uses remote sensing. The technology used is the Landsat 8 image data. [28]. Landsat 8 is a continuation of the Landsat mission, which was first launched as an Earth observation satellite in 1972 [29]. Landsat 8 data is obtained through the website earthexplorer.usgs.gov [30]. The Landsat 8 OLI image used is LC08_L1TP_129058_20230619_20230623_02_T1, in actual color from RGB bands 4, 3, and 2, where R (Red) = Band 4, G (Green) = Band 3, and B (Blue) = Band 2. Figure 8 shows the hue in Marbun Toruan Village.

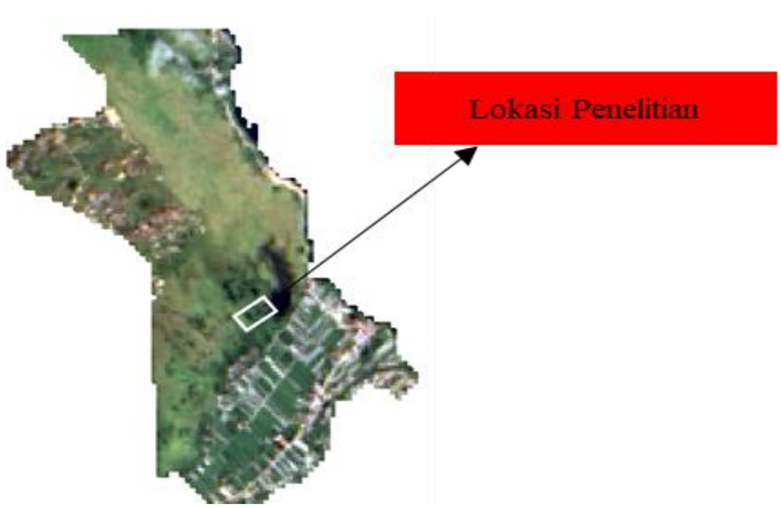

Figure 8. *True Color Marbun Toruan Village*

Based on Figure 8, we can see the hue of Marbun Toruan Village. In addition to using Landsat 8 data, the author also used USGS DEM data to obtain relief around the research area. In addition to Landsat 8 data, this research also uses DEM data. The initial stage of data preprocessing is data collection, radiometric correction, and image cropping. [31]. This DEM data is used to create a slope map derived from remote sensing that covers almost the entire Earth's surface. [32]. Figure 9 shows the slope-processing results, which depict the slope map.

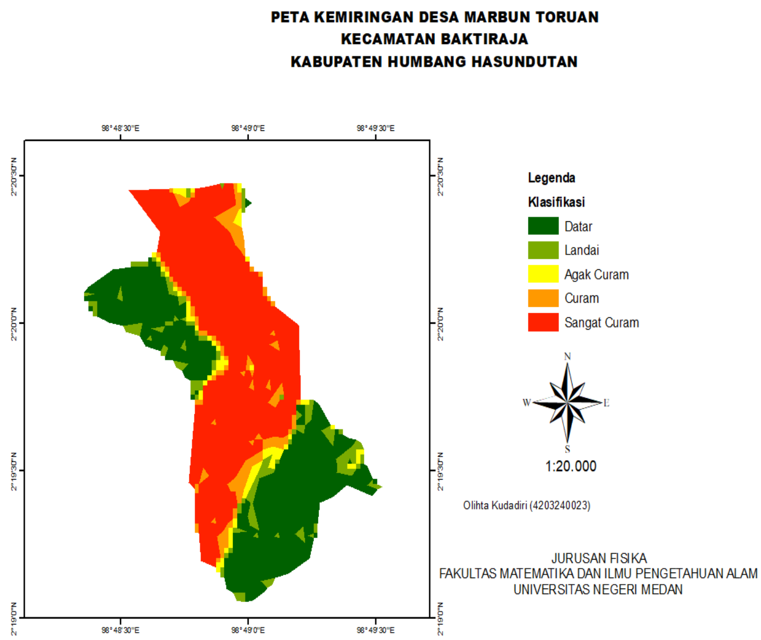

Figure 9. Slope of Marbun Toruan Village using DEM data

Based on Figure 9, the Marbun Toruan area appears to be on a steep-to-very steep path, shown in orange and red.

DISCUSSION

A. Geoelectric

Track 1

Track 1 was obtained using ARES geoelectricity. Figure 3 shows that the research area has a resistivity range of 900 Ωm to 3000 Ωm, with values at depths of 1.25 m to 12.4 m, interpreted as sand, dry gravel, and tuff. The study area is a topographic region of hills and mountains, with an altitude of 940 meters above sea level. This indicates that the study area is on steep hills. Based on the results of geoelectric interpretation, it is found that track 1 is dominated by dry gravel, referring to the research of [33] obtained dry gravel with a resistivity of 1556.2 Ωm with a thickness of 19.5 m. This gravel is usually used for construction and to improve slope stability and prevent collapse. In addition, track 1 obtained tuff rock spread at a depth of 1.25 m - 12.4 m, referring to previous research [34] obtained tuff rock with a resistivity of 2600 Ωm - 4601 Ωm. Tuff rocks generally undergo weathering or erosion, which is then transported by water and deposited as alluvium, sand, gravel, and other materials.

Track 2

Track 2 was obtained using ARES geoelectricity. Figure 4 shows that track 2 has a lower resistivity than track 1. This is because the measurements in track 2 have more vegetation than those in track 1. This track is in shrubs, where the soil and rocks can still absorb water. In addition, the higher the height, the higher the resistivity. The resistivity of 500 - 1100 Ωm, which is interpreted as alluvium, sand, and gravel, indicates that this track is likely to be subject to landslides. This is because when the slope of the land is too steep, gravity can make the rock unstable. Track 2 is dominated by tuff rocks, evenly distributed to a depth of 12m. These rugged rocks are hard and help support the slope, keeping it stable. According to [35], tuff rock is a water-bearing lithology. The research [36] found that this tough rock is used for development purposes. This shows that this rock can be used according to regional conditions.

Track 3

Track 3 was obtained using ARES geoelectricity. Figure 5 shows that track 3 has the same resistivity as track 2. However, rugged rocks are scattered in several places. This indicates that the tuff rock has undergone compaction or remodeling. This overhaul then spreads around the rugged rocks, producing alluvium, gravel, and sand deposited by water. In addition, on track 3, there is a boulder estimated to be alluvium, gravel, and sand. These rocks indicate that landslides may occur in the area. This is because the rock falls within the scope of the surrounding tuff. At the same time, the sand and gravel are also the result of tuff rock compaction. However, these rocks are harder and sturdier than the alluvium, sand, and gravel.

Based on the discussion of geo-electrical trajectories 1, 2, and 3, it can be seen that the research area is dominated by tuff rocks, some of which have undergone remodeling. The overhaul produces alluvium, dry gravel, and sand deposited by water. Based on research [37] explains that the Toba Tuff is used as building material. Generally, the constituent rock of a temple is andesite. [38]. However, based on research [39] found that the building materials of temples around Prambanan are tuff rocks and [40] also found rugged rocks as the foundation of the Prambanan Temple. In addition, [41] found that the constituent rock of Sirih Temple is tuff and [42] found that the constituent rock of Ronggeng Temple is tuff. There is also [43]The constituent rock of Sirih Temple is tuff; because of the abundance of tuff around the area, they were inspired to build Sirih Temple using tuff. Research [44] In his research, he found a previously unknown type of tuff rock on the base of the ancient temple in Sant'Omobono, Rome. This proves that tough rock can also be used as a foundation material for temples. This is because tuff rock is coarse, delicate, and layered.

B. Remote Sensing

In Figure 8, there is a variation of contrasting rock tones in the image. According to [45], the bright green color represents plantation areas, dark green rice fields, white roads and settlements, and bluish-white coastal regions. [46] said that the variation of hue from Figure 8 shows that the Marbun Toruan Village area is included in the Uniform group which is defined as containing Alluvium type rocks referring to research [7] getting the hue in Lobu Tua village is included in the uniform hue which means that the area is an Alluvium area, which is sedimentary rock consisting of material deposited by flowing water. This material can be sand, mud, gravel, or silt. This material comes from the overhaul of rugged rocks. Based on the slope map in Figure 9, the research area falls within the steep-very steep category, with a slope of 25%-45%. Based on the slope table [47] and table [48], it can be said that this area has a hilly-sloped steep/steep slope topography, so it can be determined that the rock types are igneous effusion/lava, clay/shale, silt, marl, and tuff. Based on the geological map [49], Marbun Toruan village is located in the Toba Tuff formation (volcanic rock), which consists of tuff composed of rhyolite, partially grounded, and Pliocene in age. This area is also included in the alluvium formation, which consists of gravel, sand, mud, fan fanglomerate, diatome soil, and coral. Figure 10 shows the geological map of the study area.

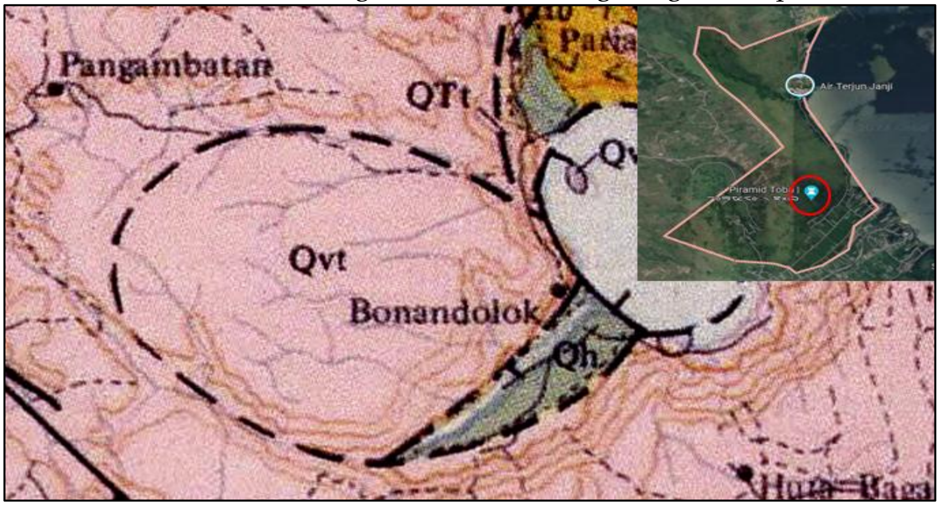

Figure 10. The geological map of Marbun Toruan Village indicates that the study area is mainly classified as Qvt, while certain portions are categorized as Qh.[49]

Based on Figure 10, the constituent rock formation in the study area is Qvt and is partly classified as Qh. This is in accordance with the results obtained using Landsat 8 and USGS DEM, the results of which are in Table 6.

Table 6. Image data table

Imagery	Results	Rock Type	Geology
Landsat 8	Rona *Uniform*	Alluvium	Qh (Aluvium)
DEM	*Slope* 25% - 45%	Tuff	Qvt (Tufa Toba)

Based on research [37]explains that Toba Tuff rocks are used for building materials rather than for road paving. Marbun Toruan Village is included in the Qh or Alluvium and Qvt or Toba Riodasite formations. This shows that the rocks in Marbun Toruan Village are the result of the breakdown and compaction of tuff into other rocks. This indicates that the results of geoelectrical interpretation and imagery are in harmony, because the rocks obtained are tuff and alluvial rocks derived from the destruction of tuff stones.

CONCLUSION

Based on the results of data processing using the Wenner-Schlumberger configuration geoelectric method, the rock resistivity value of 500 Ωm – 3000 Ωm is interpreted as alluvium and tuff rocks. While mapping results at the Toba Pyramid Site in Marbun Toruan Village, using image data, show that the area is dominated by alluvium and tuff. To strengthen the research results, GPR and Coring are needed for further research.

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