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UTILIZATION OF CROSS-SECTION DIGITIZATION FROM 2D GEOELECTRIC RESULTS TO VISUALIZE THE SHAPE OF THE SAUNG CAVE CAVITY AS A GEOEDUCATIONAL POTENTIAL

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Abstrak

Penelitian ini dilakukan untuk mendeteksi dan memvisualisasikan keberadaan rongga gua di kawasan Gua Saung Penggembur, Lombok Tengah, dalam rangka mendukung upaya pengembangan kawasan tersebut sebagai fasilitas geoedukasi. Metode yang digunakan adalah geofisika resistivitas 2D dengan konfigurasi Wenner pada empat jalur pengukuran. Data yang diperoleh diolah menggunakan perangkat lunak Res2dinv untuk menghasilkan penampang bawah permukaan. Hasil penampang dari keempat jalur pengukuran menunjukkan nilai yang terus meningkat seiring bertambahnya kedalaman. Hasil ini kemudian didigitalisasi untuk memvisualisasikan bentuk gua berdasarkan nilai resistivitas yang diperoleh. Rongga gua diasumsikan memiliki nilai resistivitas tinggi berkisar antara 725 hingga 1000 Ωm. Nilai-nilai ini ditemukan pada kedalaman 2,5 m, atau bahkan lebih dalam. Hasil ini menunjukkan bahwa keberadaan rongga gua bervariasi di setiap titik. Kondisi ini didukung oleh pengamatan lapangan yang menunjukkan adanya lubang di atas permukaan. Hasil ini ditafsirkan sebagai indikasi keberadaan rongga atau lorong gua. Studi ini memberikan gambaran awal kondisi geologi bawah permukaan dan menunjukkan efektivitas metode geofisika 2D dalam mengidentifikasi zona berongga secara non-invasif. Temuan ini penting untuk mendukung eksplorasi geologi lebih lanjut, pelestarian kawasan karst, dan pengembangan potensi geoedukasi sebagai laboratorium alam

Kata kunci*: Geoedukasi; rongga gua; konfigurasi wenner; resistivitas*

Abstract

[Title: Utilization of Cross-Section Digitization from 2D Geoelectric Results to Visualize the Shape of the Saung Cave Cavity as a Geoeducational Potential] *This study was conducted to detect and visualize the presence of cave cavities in the Saung Penggembur Cave area, Central Lombok, to support efforts to develop the area as a geo-educational facility. The method used was 2D resistivity geophysics with a Wenner configuration on four measurement lines. The data obtained were processed using Res2dinv software to produce subsurface cross-sections. The cross-section results from the four measurement lines showed continuously increasing values with increasing depth. These results were then digitized to visualize the cave's shape based on the obtained resistivity values. Cave cavities were assumed to have high resistivity values ranging from 725 to 1000 Ωm. These values were found at a depth of 2.5 m, or even deeper. These results indicate that the presence of cave cavities varies at each point. This condition is supported by field observations showing the presence of a hole above the surface. These results are interpreted as an indication of the presence of cavities or cave passages. This study provides an initial overview of subsurface geological conditions and demonstrates the efficacy of the 2D geophysical method in non-invasively identifying hollow zones. These findings are important for supporting further geological exploration, the preservation of karst areas, and the development of geoeducation's potential as a natural laboratory.*

Keywords*: Geoeducation; cave cavity; wenner configuration; resistivity*

INTRODUCTION

Caves are one of the geological features that hold significant value in earth science studies, serving not only as objects of exploration, conservation, and tourism [1–3], but also possessing great potential as a natural medium for geological and geophysical education [4]. Caves are an effective tool for introducing geological processes, karst environmental dynamics, and the importance of natural resource conservation to the general public, particularly young people and academics [5,6]. The use of caves in education is known as geoeducation [7]. In this context, caves fall under the category of geoheritage due to their unique scientific, educational, and ecological value, making them an ideal primary focus for geoeducation activities [8]. Karst areas possess high educational potential as they reflect the interaction between geological, hydrological, environmental processes, contain valuable and unique paleoclimatic and archaeological information compared to other sites [9].

One area with great potential for geoeducation development is the Saung region, which morphologically and lithologically belongs to the karst zone (limestone) [10]. Geologically, the Saung region is composed of limestone formations that have undergone a long geological process of dissolution (karstification), resulting in the formation of underground cavities, fractures, and cave passages [11]. Such a cave can serve as a direct source of knowledge for understanding the lithogenic processes of carbonate rocks and the dynamics of underground systems [12]. Moreover, Saung Cave serves as an important habitat for various fauna, such as bats, owls, and other animals, making it relevant for studies on biodiversity and cave ecology [10,13].

Karst areas such as Saung Cave have great potential to be developed as geo-education sites due to their rich geological features, such as cave passages, fissures, and underground cavities. However, before they can be utilized for such purposes, it is necessary to accurately identify the existence and distribution of caves to ensure safety, conservation, and educational value. Identifying the presence of underground caves in karst regions often faces challenges, such as limited field access, the risk of cave collapses, and the importance of preserving the environment, thereby requiring safe and non-destructive exploration methods. In this context, the resistivity geophysical method has proven effective in detecting the presence of underground caves by identifying variations in resistivity values that reflect changes in lithology, fractures, or dissolution zones. Previous studies, such as Pagán et al. (2013), emphasize the importance of using high-resolution instruments to accurately penetrate subsurface depths [14]. A study by Ardi & Iryanti (2009) at Dago Pakar Cave, Bandung, demonstrated the success of the Wenner-Schlumberger configuration geophysical method in mapping subsurface profiles laterally and vertically, supporting the effectiveness of this approach in cave exploration [15]. Research by Hutomo et al. (2016) in Bandung Cave, Sukolilo, also showed that caves could be detected at depths of 7–27 m with resistivity values ranging from 724–1000 Ωm, proving that this method is capable of effectively identifying cave lineways up to several tens of meters below the surface [16].

Although there have been many studies using geophysical methods for subsurface modeling, there are still no studies that specifically integrate these modeling results for geoeducation purposes in the study area. Saung Cave is suitable as a geoeducation site because it has scientific, educational, and geological tourism development potential [1,10,17,18]. In the context of geoeducation, the importance of cave locations is increasingly recognized as a valuable resource for promoting geological knowledge and heritage [19–21]. Against this backdrop, this study aims to visualize the presence of Saung Cave using 2D geophysical methods as a basis for developing geoeducational potential at the study site.

METHOD

This research was conducted in the Saung Cave area located in Penggembur Village, Jonggat District, Central Lombok Regency, West Nusa Tenggara Province. Geographically, the research location is at coordinates 8°45'17.4"S and 116°17'53.6"E. This cave is located in a community-owned rice field and plantation area, approximately 500 meters from residential areas. In this survey, the determination of the measurement point location took into account the steep, rocky topography of the area and some areas covered by bushes, thus complicating access to installing electrodes. Based on these conditions, four geoelectric method measurement lines were determined with the following provisions: one line has a length of 161 m with an electrode spacing of 7 m, while the other three lines each have a length of 115 m with an electrode spacing of 5 m. The distribution of measurement points and the design of the research survey are shown in Figure 1. Adjustments to the length and spacing were made to allow optimal electrode installation without significantly disturbing natural vegetation.

All measurements were performed using a Wenner configuration with a total of 24 electrodes. The Wenner configuration provides good vertical resolution and high sensitivity to horizontal layers, making it suitable for identifying lithological variations and detecting cavities in karst environments. An illustration of the Wenner configuration is shown in Figure 2.

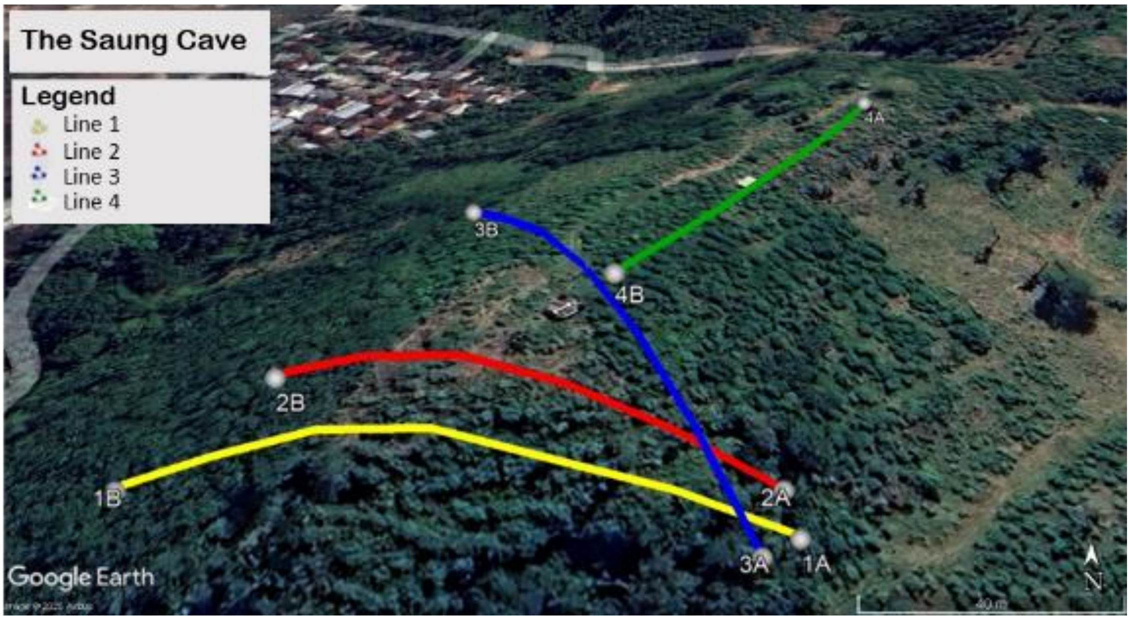

Figure 1. Measurement lines marked from position A to B . Line 1A to 1B (Line 1 - Yellow), Line 2A to 2B (Line 2 - Red), Line 3A to 3B (Line 3 - Blue), and Line 4A to 4B (Line 4 - Green).

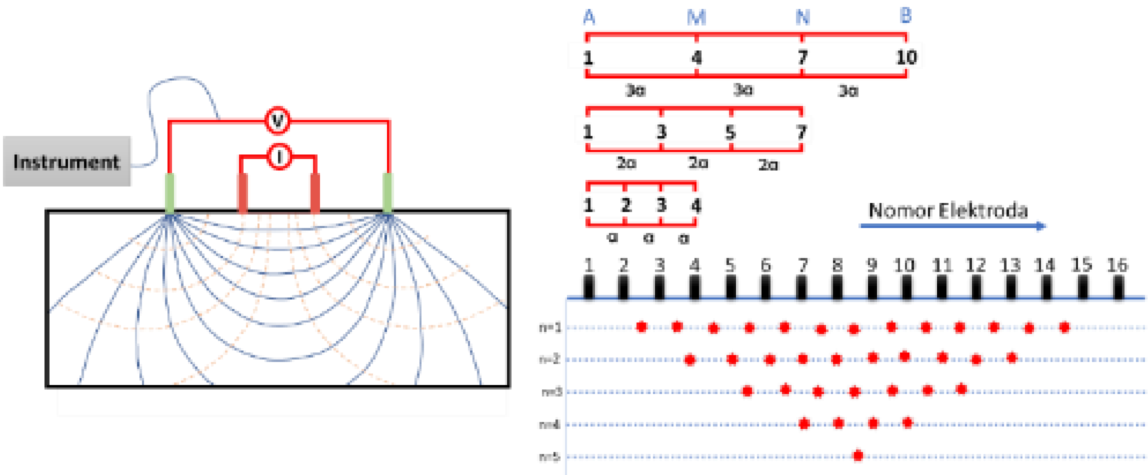

Figure 2. Wenner Configuration Electrode Arrangement

The data obtained from the field measurements are the injected current (I) and the measured potential difference (V) on the resistivity meter. The instrument used is the IRES T300f resistivity meter. Based on the field data, the apparent resistivity (ρ_a) can be obtained using equation 2, but the value of K (geometric factor) must be determined first. The value of K depends on the electrode configuration used [22], where in this study, the Wenner configuration is used with the following equation:

$$K = 2\pi a \tag{1}$$

$$\rho_a = K\frac{V}{I} \tag{2}$$

The obtained ρ_a value is the initial resistivity value calculated directly from field measurement results. This value is used as input data in the inversion process to obtain the actual resistivity value in the form of a 2D subsurface cross-section. This inversion process is carried out using the Res2dinv software version 3.53g, through the least-squares inversion method. The Res2dinv results consider the spatial distribution of electrodes and variations in resistivity with depth and horizontal position to produce a resistivity model that approximates the actual geological conditions.

With the help of this software, the interpretation of the presence of cavities, weathering zones, fractures, or rock layers can be performed more accurately and directionally. Field measurement data processed using the Res2dinv software produces 2D resistivity cross-sections related to subsurface lithological variations. The objective of this study is to visualize the shape of the Goa Saung cave. The steps taken to achieve this objective include applying a digitization process to the obtained 2D resistivity cross-sections. The expected final result is an illustration of the depth depicting the shape of the cave cavity, thereby strengthening the visual and educational interpretation of the subsurface structure. To support this result, resistivity cross-sections based on elevation values are also added to determine whether the elevation values at each measurement point influence the shape of the cave cavity produced.

RESULT AND DISCUSSION

The research location is in Saung Penggembur Cave, which has limestone formations that show intensive secondary dissolution and deposition processes (Figure 3). One of the distinctive features found is the presence of stalactite-like formations, namely cone-shaped mineral deposits that hang from the ceiling of the rock cavity (Figure 3b). These structures are formed due to the precipitation of calcium carbonate ($CaCO_3$) from water that seeps through limestone cracks and drips slowly [23]. This phenomenon indicates that the area once experienced (or still experiences) environmental conditions that support the formation of speleothems, such as the circulation of carbon dioxide-rich underground water.

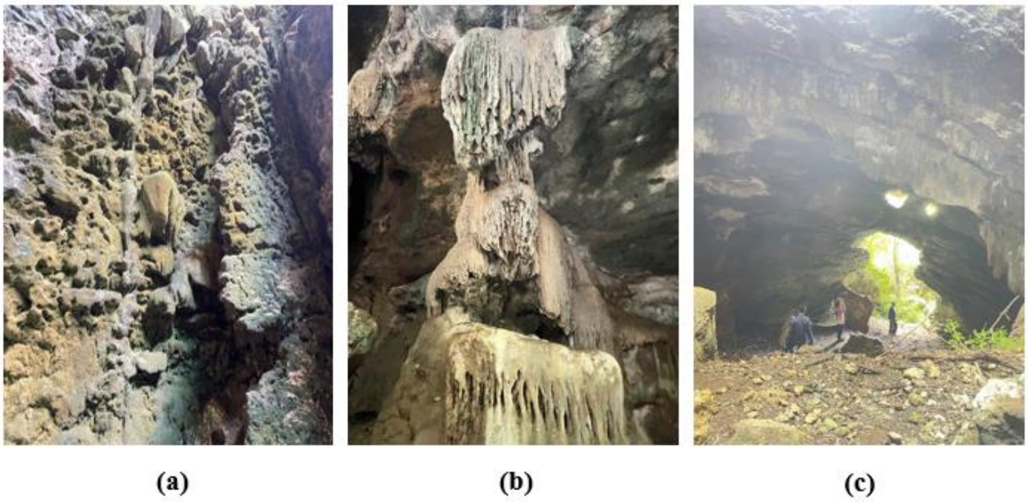

Figure 3. Saung Pengembur Cave (a) limestone outcrop, (b) limestone with stalactite-like formations, (c) curved shapes on the walls and ceiling of the cave.

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Based on the measurement trajectory in Figure 1, the inversion results obtained for each trajectory are presented in the form of a two-dimensional (2D) color cross-section that represents the variation in resistivity laterally and vertically. In the cross-section results obtained, significant variations in resistivity values are observed along the profile, as shown in Figure 4. Based on these cross-sections, digitization was performed to generate visual representations or illustrative diagrams related to Saung Cave. Digitization was determined based on resistivity values, referencing two previous studies indicating the presence of cave voids. The research by Hutomo et al. (2016) in Bandung Cave indicated that cave voids begin to appear at resistivity values between 724 – 1000 Ωm [16]. Other studies also showed that the cave edge transition zone was within the resistivity range > 900 Ωm [24]. Therefore, based on these values, digitization was performed at resistivity values indicating the presence of cave voids at the study site, as specified in Table 1.

Table 1. Position of digitization based on the resistivity value of each line.

Line	Digitization position	Resistivity Value
1	Between colors	± 983 Ωm
2	Between colors	± 1002,5 Ωm
3	Between colors	± 724 Ωm
4	Between colors	± 777 Ωm

On lines 1, 2, and 3, the digitized locations were between brown and orange. However, on line 4, the digitization was performed on contour colors between yellow and brown. This difference occurs because the digitization process focused not on color but on resistivity values indicating the presence of cave cavities. The digitized results from each measurement line are below the 2D cross-section inversion results in Figure 4 (A1, B1, C1, and D1).

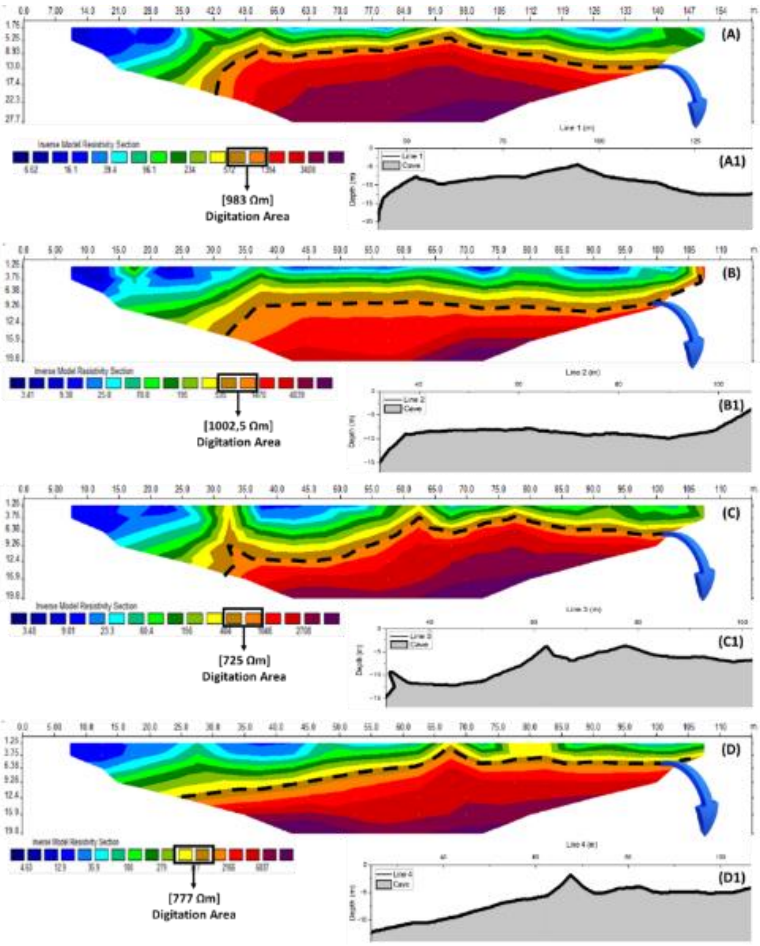

Figure 4. The results of the inversion (A, B, C, and D) and digitization of the cross-sectional line (A1, B1, C1, and D1). Line 1 (A and A1), Line 2 (B and B1), Line 3 (C and C1), and Line 4 (D and D1).

The cross-sectional shapes obtained on lines 2, 3, and 4 (Figures B, C, and D) produce the same depth value of 19.8 m because the spacing and length of the lines are uniform. Meanwhile, section 1 (Figure A) shows a deeper cross-section result, at a depth of 27.7 m. This is because the length and spacing between electrodes for section 1 are greater than those for the other sections (the reason for this has been explained in the methods section). In the four cross-sections presented, cave cavities begin to appear at a depth of 2.5 m and may potentially extend deeper, as indicated by the cross-section digitization results.

The cross-section digitization results for the measurement lines are shown in Figures A1, B1, C1, and D1. The visualization of the cave on lines 1, 2, and 3 (Figures A1, B1, and C1) appears curved, while on line 4 (Figure D1), the cave representation appears to rise upward toward the surface, starting from a depth of 12.5 m and ascending to 4 m. The interpretation results will be further strengthened by adding elevation values to help identify the topography, whether the area is classified as a steep slope or not (Figure 5). Differences in elevation contours between profiles indicate that the morphological and topographic conditions of the study area influence the interpretation of subsurface geology, particularly regarding the potential shape of cave cavities.

The topographic elevation along the entire line generally ranges from 130 to 150 m above sea level with varying contours. Lines 1, 2, and 3 show elevations that form curves, while line 4 tends to be flatter because the route descends a hillside. These results are consistent with the previous assumption that the topography of the area influences the formation of cave voids. As shown in Figure 4, the digitized positions suspected to be cave voids on the elevation cross-section are marked with dashed white lines. This digitization aims to determine the target of this study, which is the location of the cave, so it focuses on anomalies with very high resistivity. High resistivity values ranging from 725 to 1000 Ωm are interpreted as indications of cave cavities, while low to moderate resistivity values can be interpreted as the result of limestone weathering or the accumulation of sufficiently water-saturated clay material. Cave arches are visible from the varying elevation values, as shown in Figures a, b, and c, while in Figure d the elevation values are similar, resulting in a flat topography. These results indicate that contrasting elevation values can reveal the shape of cave arches more clearly.

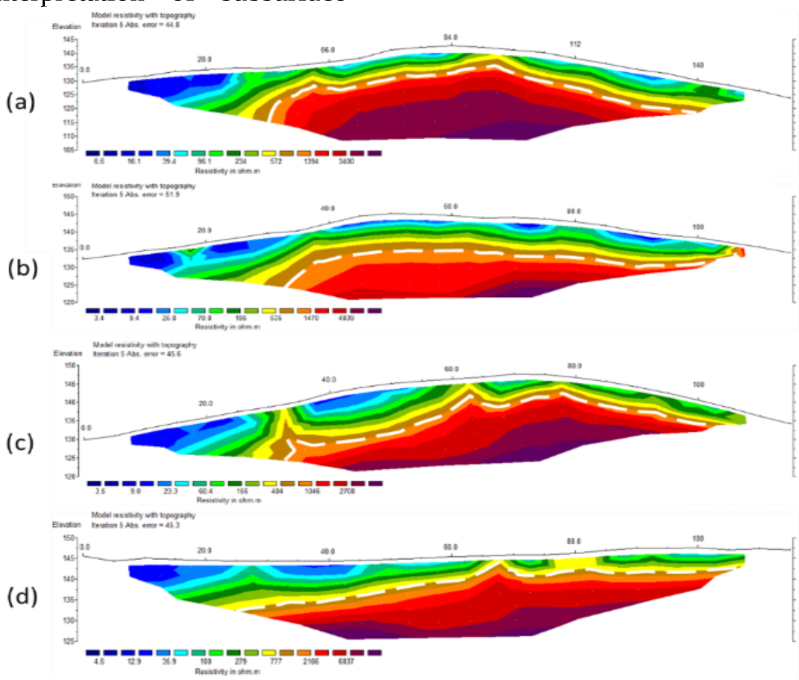

Figure 5. Results of the measurement line based on the elevation value of the study area (the dotted white line indicates the position where digitization was performed). (a) Line 1, (b) Line 2, (c) Line 3, and (d) Line 4.

The measurement line reflects the hilly surface commonly found in karstified limestone areas. The resistivity values obtained along each line show a continuous increase with depth. The resulting cross-section reveals a fairly symmetrical layer structure, with high-resistivity zones forming mounds beneath the surface. In particular, the curved shape of the high resistivity zone reinforces the assumption of the existence of an air-filled cave passage, in line with the physical characteristics of natural cave systems. However, information regarding the depth of the cave is not only obtained from 2D resistivity measurements; during the field survey, a cave cavity was also found to form a large hole above the surface. This hole allows light from outside to penetrate the cave, so information related to this has also been added to the illustration created (Figure 6). Based on the results of 2D resistivity measurements, digitization, and field observations, an illustration of the depth of Saung Cave was created. Saung Cave was found at different depths from each point above the surface. These results are presented in the form of a cave illustration in Figure 6. Caves can be found above the surface (cave openings) or at specific depths, as indicated by the white lines in the cave illustration.

Overall, the combination of these four cross-sections demonstrates a diversity of subsurface structures that can be linked to karstification, weathering, and the potential for cavities, which are common characteristics of limestone geological environments. These results also demonstrate that the geoelectric method is highly effective in identifying differences in subsurface lithology and detecting the presence of hidden geological features such as cavities and fractures. This interpretation is consistent with the surface geology of the research site, which is dominated by layered limestone and exhibits various landforms typical of karst areas. Visual observations in the field through photographic documentation indicate that the interior structure of the cave exhibits curved shapes on the walls and roof, intensive dissolution patterns, and cave openings visible above the surface of the line (Figures 3 and 5a). Then, geophysically, these shapes are represented by high, curved resistivity anomalies in the digitized cross-section (Figure 4).

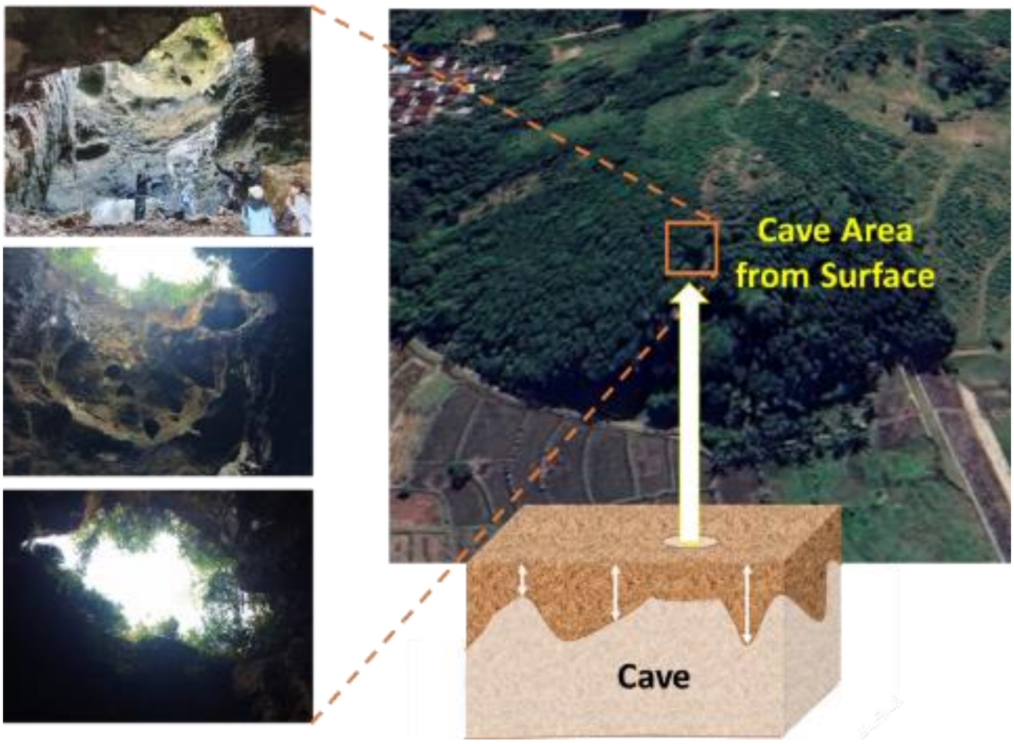

Figure 6. Illustration of Saung Cave based on 2D resistivity results and field observations.

The Saung Penggembur Cave area has great potential to be developed as a natural laboratory-based geoeducation site. This cave can be utilized as a learning tool for studying karst morphology, hydrogeology, and cave ecosystems. The presence of cavities, fractures, and dissolution zones, clearly visible in the geoelectric data and the cave's physical condition, provides a valuable hands-on learning medium for students. Furthermore, the application of geoelectric methods in educational activities can also introduce non-invasive subsurface exploration technologies. However, to obtain a more comprehensive and accurate understanding of the subsurface structure in this area, further verification is needed using other geophysical methods such as Ground Penetrating Radar (GPR), seismic refraction, or even underground lidar exploration to map the cavities in three dimensions. This multidisciplinary approach will greatly support the use of caves not only as objects of scientific research but also as a medium for sustainable geological education

CONCLUSION

This study successfully visualized the subsurface depth and identified the presence of cavities in the Goa Saung Penggembur area using the Wenner configuration 2D resistivity geophysical method. The results of the resistivity cross-section interpretation showed the presence of zones with high resistivity values between 725 - 1000 Ωm distributed at varying depths. The cross-section results obtained indicate the presence of cavities or cave passages containing air. The varying depths of the cave from various measurement points are supported by field observations that found cave openings above the surface, as well as digitization curve results showing that the Saung Cave cavity was found at a depth of 2.5 m and has the potential to be even deeper. The curved and symmetrical resistivity structure reinforces the assumption of an underground cave system formed by the karstification of limestone. The presence of cavities and the geological characteristics of the karst area indicate that Saung Cave has great potential to be developed as a geo-education site. This cave can be utilized as a natural laboratory to support conservation efforts and enhance geoscience literacy among the community and students. Additionally, in-depth studies on geo-educational aspects and the development of field learning materials are also important to optimize the utilization of Goa Saung as a sustainable educational resource.

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