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APPLICATION OF VERY LOW FREQUENCY (VLF) METHOD FOR UNDERGROUND RIVER ESTIMATION IN DONOROJO SUB-DISTRICT, PACITAN

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ABSTRACT

Pacitan is included in the Gunung Sewu karst area in the Southern Mountain Zone, and carbonate rocks dominate the constituent rocks. Karst has a unique drainage system because it is dominated by subsurface flow. This research was conducted in Cemeng and Klepu villages, Donorojo sub-district, Pacitan, with 4 track data. Data were collected using the very low frequency electromagnetic (VLF-EM) method with a track length ranging from 200-450 m, a measurement spacing of 5 m, and a transmitter frequency of 19.8 kHz. Data processing uses filtering and inversion, resulting in a cross-section of resistivity values. Based on the subsurface resistivity cross-section profile, the cavity in the carbonate rock layer with a resistivity value of 0-500 Ωm is identified as an underground river. The underground river is found on tracks 1, 2, 3, and 4 near the surface, with a depth of about 30 m below the surface.

Keywords: Resistivity; Underground River; VLF-EM

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INTRODUCTION

Gunung Sewu Karst, located in the Pacitan region, is a carbonate hilly area with high and steep topography. Karst has unique characteristics, with many streams found below the surface. The constituent rocks are carbonate rocks with high solubility, making it easy for rocks to pass rainwater that falls on the ground. Water flowing down the surface through holes will fill the cavities in the karst, which will then accumulate in a flow pattern and form an underground river. Water availability in karst areas during the dry season is a yearly problem, as is the case in Donorojo District, Pacitan. Based on data from the Pacitan Regency BPBD in 2019, as many as 8 sub-districts in Pacitan experienced drought. One of the areas that is prone to and is included in the low-medium drought class zone is Donorojo Subdistrict [1].

Being in an area with a rock composition dominated by carbonate rocks makes the research area difficult to reach in the presence of surface water. Especially during the dry season, surface water sources will experience a decrease in discharge because more rainwater flows directly into the subsurface water system. However, karst areas have potential groundwater to support water supply during the dry season through karst groundwater [2]. The current problem is that it is difficult to know the existence of most underground rivers. This is due to their location several tens of meters from the ground surface.

The very low frequency electromagnetic (VLF-EM) method is one of the geophysical methods that can be used to find suspected underground rivers [3]. The VLF-EM method can detect a cavity based on the contrast of conductivity and resistivity of rocks[3]. Underground rivers are cavities in karst that are formed due to water flow. According to Kuswanto's research (2005), subsurface cavities filled with water have a very small resistivity value, whereas empty subsurface cavities have a greater resistivity value than the surrounding rocks [4]. Research using the VLF-EM method has been conducted by McNeill (1990) for groundwater exploration and mapping of contaminated groundwater[3]. Bosch & Müller (2005) conducted research using the VLF-EM method in karst areas for mapping karst structures (faults) [5], Sungkono et al. (2016), Faizal et al. (2017), and Jamal & Singh (2018) used the VLF-EM method for mapping underground rivers in karst areas [6-8]. Data processing using the VLF-EM method produces subsurface resistivity distribution cross-sections by performing data inversion. The VLF-EM inversion process is used to obtain rock resistivity with a response that matches the field data and to obtain depth information [9]. The rock resistivity distribution is then used to identify the position of underground rivers in the Pacitan karst area.

Geology

Van Bemmelen (1949) divided the southern mountains into southern and northern parts. The Gunung Sewu karst area is the southern part, which stretches from Yogyakarta to eastern Pacitan [10]. Pacitan Karst is part of the Gunung Sewu Karst region of the Southern Mountain Zone in East Java. The Southern Mountains Zone is formed due to a block uplift that slopes to the south. The stratigraphy of the Pacitan area is comprised of marine deposits that have been uplifted to the surface of the shallow sea. Van Bemmelen[10], The Pacitan karst area comprises carbonate deposits and results from volcanic activity.

The study area belongs to the Wonosari Formation, which is dominated by layered limestone, reef limestone, and marl. The area is characterized by undulating hills and limestone mountains. Plains are located along the coast and river valleys. The hilly units are dominated by limestone, which is widely distributed in the western and eastern parts of the Pacitan district. Surface appearances like doline, uvula, and underground river flows indicate karst development in this area.

Very Low Frequency

The Very low frequency-electromagnetic (VLF-EM) method is a geophysical method that utilizes very low-frequency electromagnetic signals in the 15-25 kHz range to determine subsurface structures. The principle of the VLF-EM method is that the primary electromagnetic (EM) field originating from the transmitter and penetrating the earth will interact with a conductive object that will cause an induced current. This induced current will produce a secondary field, which is then captured by the receiver as a total field, namely the primary and secondary fields[5]. VLF-EM measurements can be used to identify subsurface cavities. The position of the subsurface cavity can be described by low resistivity values, which are very high if the cavity is empty.

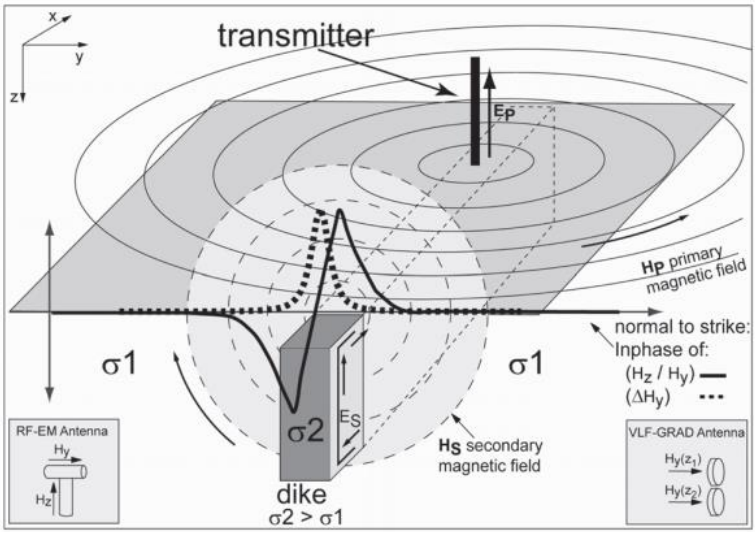

Figure 1. Working principle of the VLF method [5]

METHODS

Field data was collected in April 2022 in Cemeng Village and Klepu Village, Donorojo District, Pacitan Regency, East Java Province. There were 4 measurement tracks, with tracks 1 and 2 in Cemeng Village and 3 and 4 in Klepu Village, as shown in Figure 1. The track length ranged from 250 to 450 m. Data acquisition used a T-VLF device with a measurement spacing on each track of 5 meters and a transmitter frequency of 19.8 kHz. Measurement data consists of tilt, ellipse, Hhor, and Hver data. After the data is obtained, a *quality check* (QC) is carried out to determine whether the measurement data is good or affected by noise.

In this study, data from VLF-EM measurements are in the form of tilt and ellipse data. The tilt and *ellipse* data are then calculated using the real (*in-phase*) and imaginary (*quadrature*) components using the equation by Karous & Hjelt [11]

$$real = \tan \emptyset \times 100\% \quad (1)$$

$$imajiner = \varepsilon \times 100\% \quad (2)$$

Where ∅ is tilt and ε is ellips. Processing begins with the calculation of VLF-EM data correction. The topography-corrected data was then subjected to filtering processing, including NA-MEMD, Fraser, and Karous Hjelt filters. The Fraser filter results in the form of in-phase and quadrature graph curves, while the Karous Hjelt results are equivalent current density (RAE) cross sections. The NA-MEMD corrected in-phase and quadrature data were input data in the inversion process. VLF-EM data is then interpreted based on the processing results obtained. The flowchart of this research is as follows.

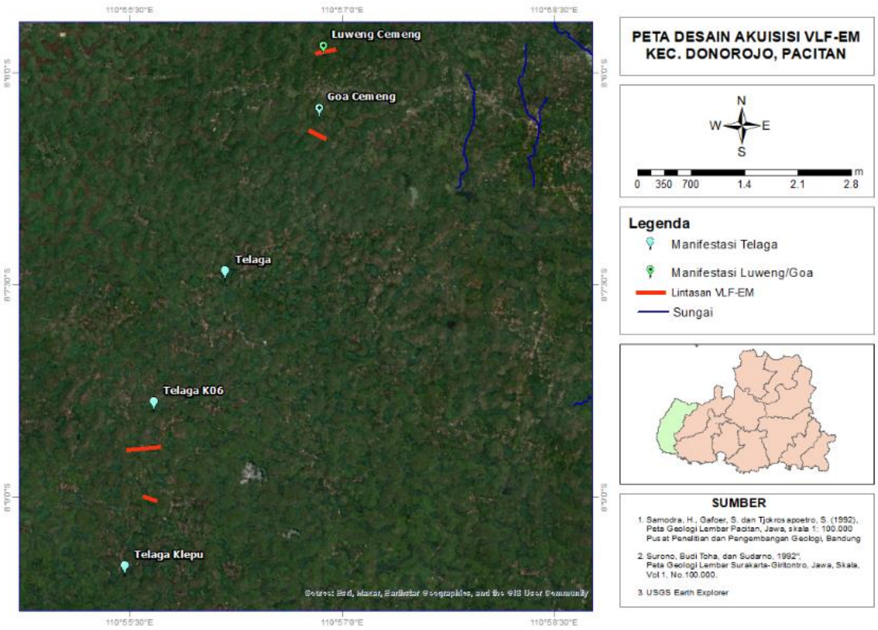

Figure 2. Research Location

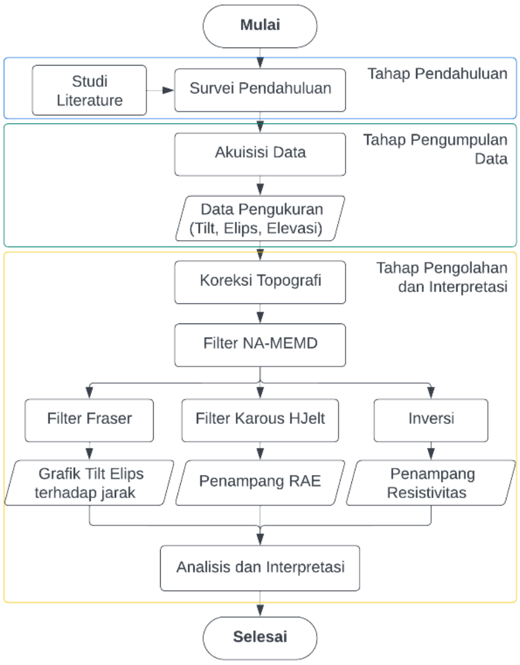

Figure 3. Research Flowchart

RESULTS AND DISCUSSION

In this study, VLF-EM data collection used T-VLF instruments with four tracks spread across the Donorojo sub-district, Pacitan. The research area has been studied using geoelectric methods [12]. Low resistivity values (<400 Ωm) are associated with underground river anomalies. Analysis and interpretation are done qualitatively from the *filtering* results. Meanwhile, quantitative interpretation used inversion results from in-phase and quadrature data. This process considers previous geoelectric surveys to reduce the ambiguity of the subsurface resistivity model. The inversion process uses an *initial* *resistivity of* 1000 Ωm by considering the results of previous studies and the research area, which is dominated by limestone [8].

Fraser Filter

Qualitative interpretation of VLF-EM data is based on Fraser and Karous Hjelt filters [11], [13]. The Fraser filter principle transforms the zero crossing into the conductive structure's optimal point (peak). Thus, a conductive anomaly is indicated when the in-phase graph reaches its maximum point. Figure 3 shows the Fraser filter results of the in-phase and quadrature components on tracks 1 to 4. The results show that conductive anomalies indicated by high in-phase values are identified on each track.

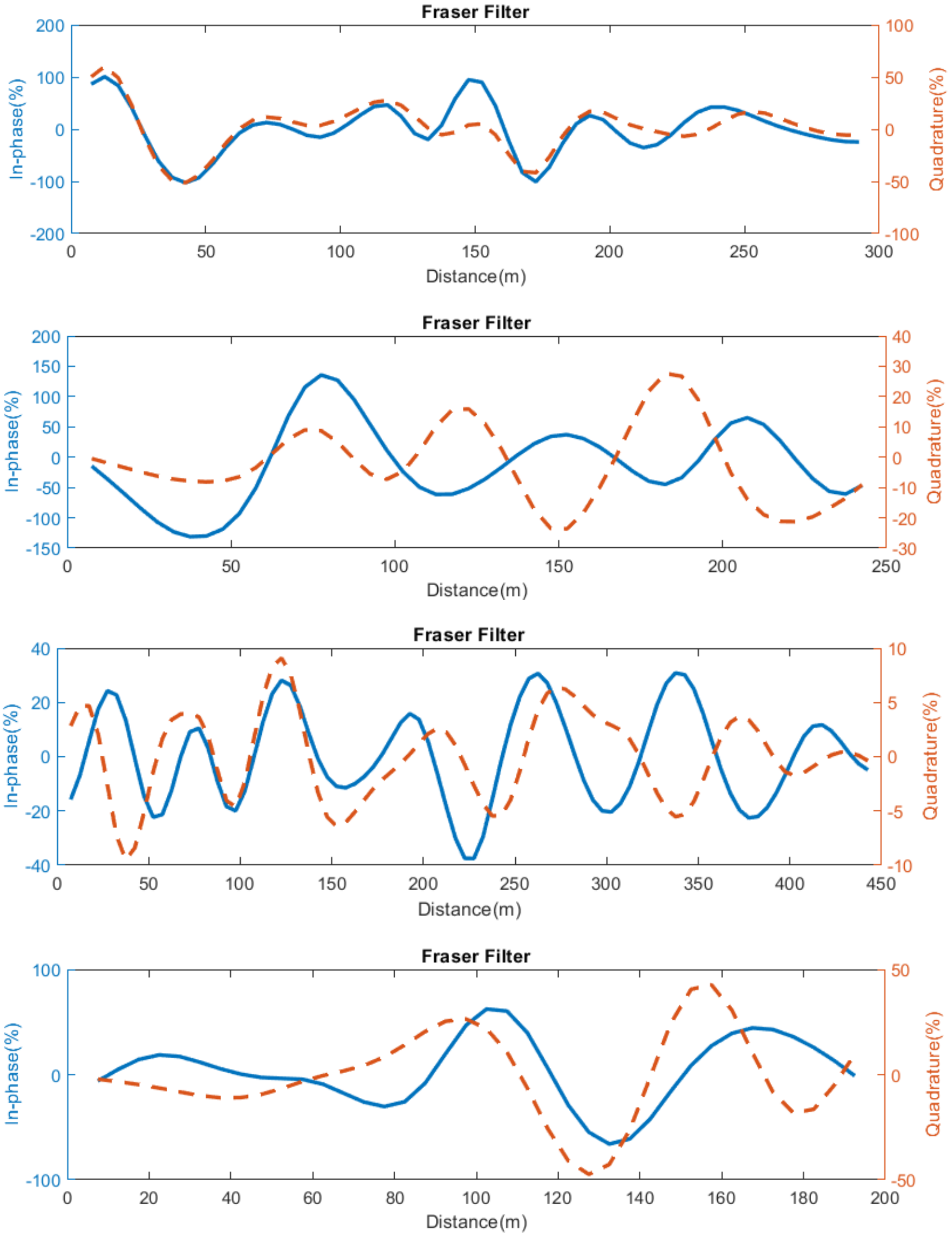

Figure 4. Fraser Filter results of VLF-EM data on tracks 1, 2, 3, and 4. The black dotted line shows the conductive anomaly area.

Karous HJelt Filter

The Karous Hjelt filter produces a cross-section of the current density distribution. Anomalies can be determined from the variation in current density, where conductive anomalies are indicated by high (positive) current density [11]. Figure 3 shows the results of the Karous Hjelt filter of VLF-EM data on tracks 1 to 4. Tracks 1 and 2 are in Cemeng Village and show high current density values at 100-155 m and 70-100 m, respectively. Meanwhile, tracks 3 and 3 are in Klepu Village and show high current meeting values in several places. In track 3, high current density was identified at 100-160 m, 250-280 m, and 330-350 m, and in track 4, it was identified at 90-115 m and 155-180 m. Conductive anomalies indicated by high current density values are considered subsurface cavities or rivers. This assumption is supported by field conditions around the research area, where manifestations of Luweng and Telaga are present. The high current density is marked with a dashed black line and visualized in red.

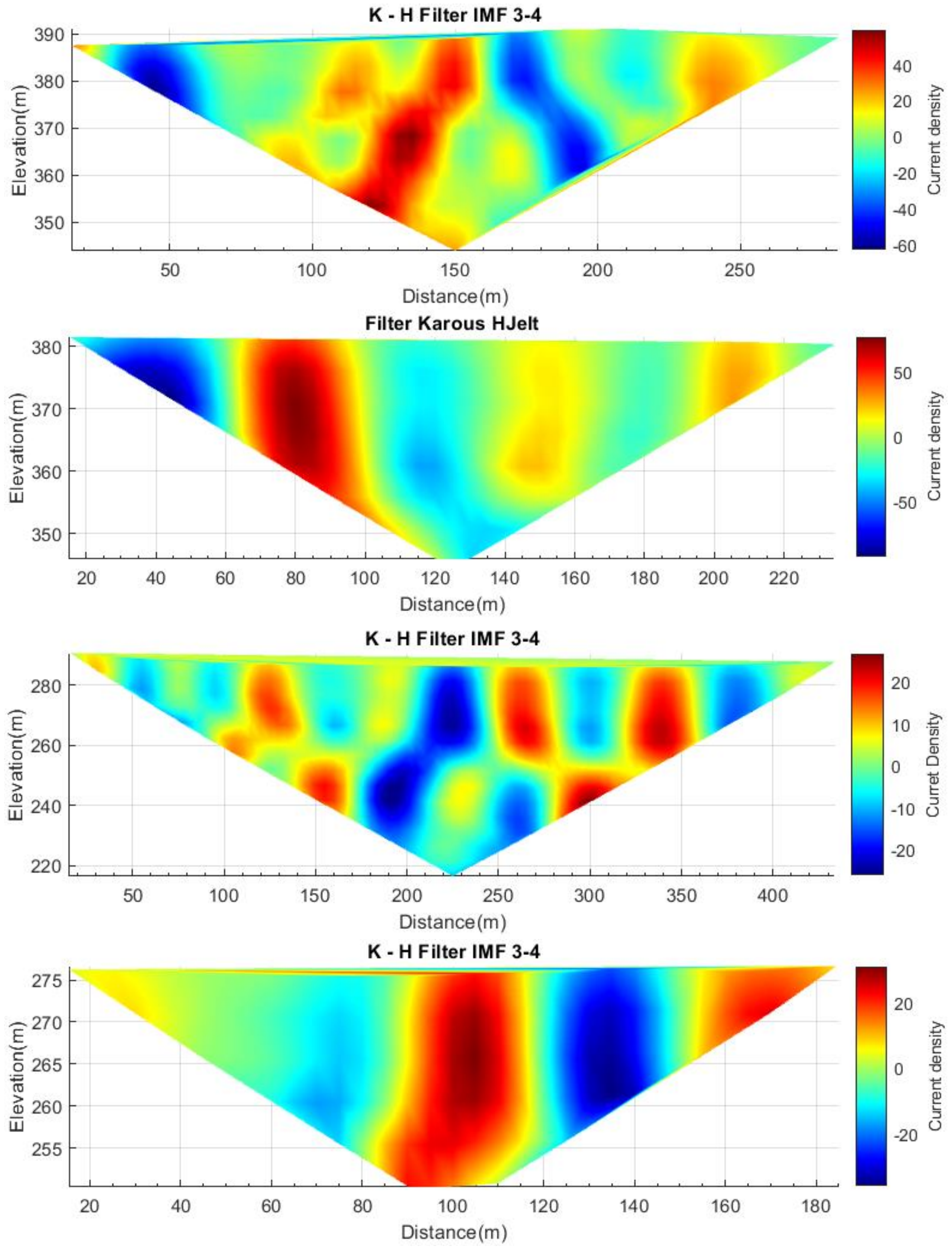

Figure 5. Karous HJelt Filter results of track 1, track 2, track 3, and track 4. Black dotted lines indicate conductive anomaly areas.

VLF-EM Data Inversion

The filtering results can provide anomalous area information laterally, while depth information is still limited [14]. Inversion is done to find out information vertically. Inversion of VLF-EM data can also obtain subsurface resistivity distribution [15]. In-phase and quadrature data were inversed using Inv2dVLF *software* by Santos (2006) [16], showing data errors of less than 10%.

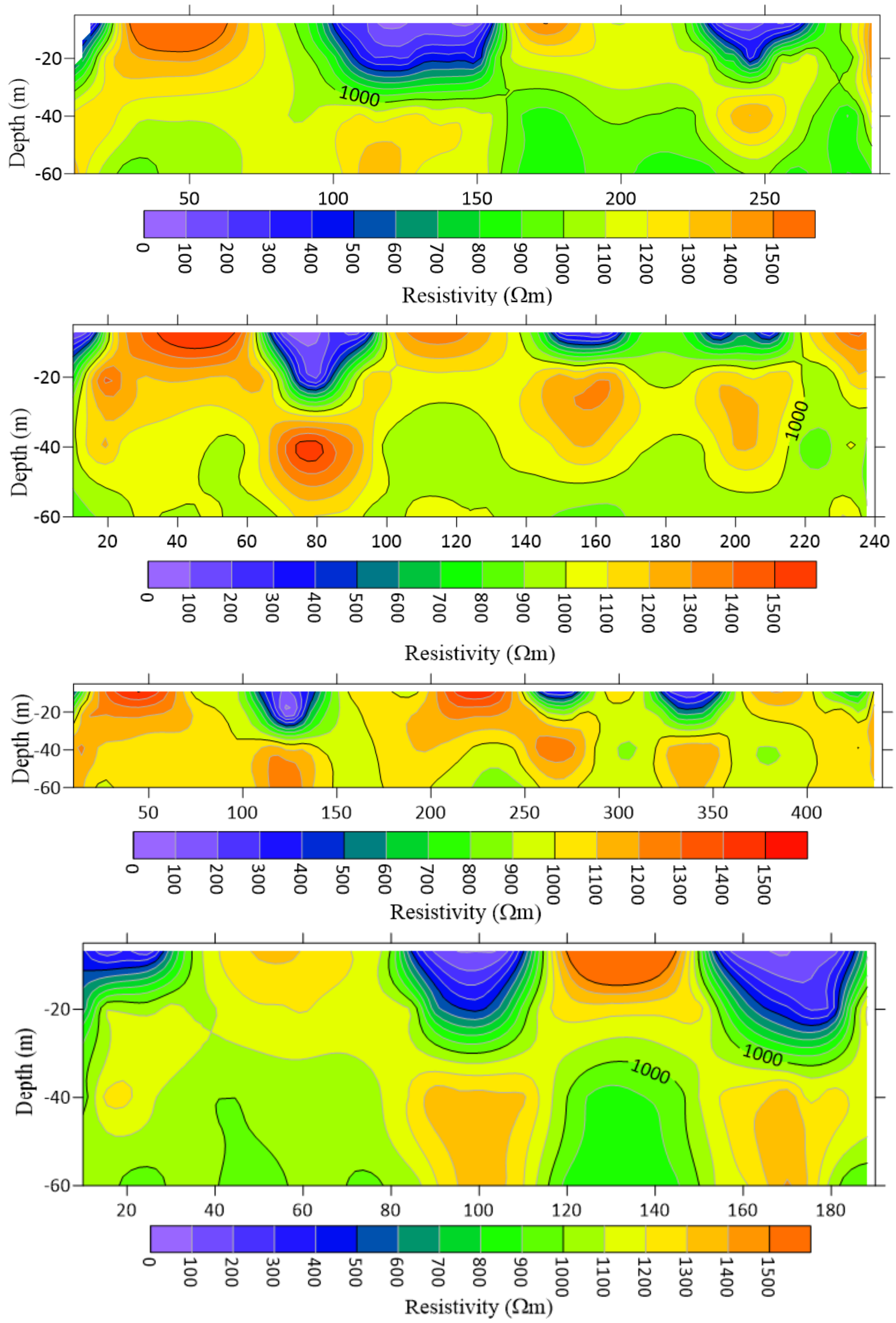

Figure 6 Subsurface resistivity distribution cross-section of tracks 1, 2, 3, and 4 with a frequency of 19.8 kHz.

The results in Figure 5 show color differences that indicate differences in subsurface resistivity values. The resistivity value *range* is 0-1500 Ωm. High resistivity values are shown in the resistivity cross-section with red color, which has a resistivity value range of > 500 Ωm. In contrast, low resistivity values are shown in blue, with a resistivity range of less than 500 Ωm. Because resistivity is inversely proportional to conductivity, the inversion results of high conductivity anomalies correspond to low resistivity. According to Sungkono et al. (2016), who researched underground rivers in the karst area of Gunung Sewu, a low resistivity value ranging from 0-500 Ωm was obtained, identified as an underground river [8]. Based on the inversion results, the underground river anomaly is well identified in tracks 1, 2, 3, and 4, at a depth of ± 30 m from the ground surface. The identified underground river has a resistivity of 0 - 500 Ωm.

Based on the analysis that has been carried out, the results show that the conductive anomalies are well identified in each of the trajectories, as indicated by high current density and low resistivity values. The conductive anomaly is identified as an underground river. The underground river was found in the limestone layer with a depth of ± 30 m. Similar results in Kuswanto's (2005) [4] research with the res2D method showed that the underground river that develops in the karst area of Gunung Sewu Pacitan is shallower (less than 100m) than the underground river in the Kasrt Gunung Sewu Yogyakarta area which reaches a depth of 200m. This assumption is also supported by manifestations around the study area, namely Luweng Cemeng, Cemeng Cave, Luweng Wareng, and Lake.

CONCLUSIONS

Based on the results and interpretation, the conductive anomaly is indicated by a positive *in-phase* graph, high current density value, and low resistivity value. The conductive anomaly is suspected to be an underground river identified on each track. The underground river is in the limestone layer with a resistivity of less than 500 Ωm and an underground river depth of less than 30 m from the ground surface.

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