seminar 2021

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Submission date: 02-Jan-2021 09:43PM (UTC+0700)
Submission ID: 1482487082
File name: 10th_ICOPIA_Revision_paper_73_2.docx (2.82M)
Word count: 1794
Character count: 9504

Very low frequency - electromagnetic (vlf-em) for detecting groundwater river patterns in *karst area of kaligambir village*

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Abstract. Groundwater flow in the limestone areas through gaps, fractures, and dissolving channels whose dimensions and directions are erratic. If the dimensions and direction of the river flow are known, it will be easier to exploit water to meet the needs of the community. The dimensions and direction of the underground river flow can be mapped using the VLF-EM method. VLF-EM measurements were carried out on 18 trajectories spread across two study areas. Each VLF-EM track has a length of 200 meters, taking data at intervals of 2 meters. Processing of VLF-EM data on each path produces a distribution of resistivity values along the measurement path. Resistivity values around Bleri Cave range between 53 Ωm - 685 Ωm, underground river flow is located at a depth of ± 40 meters and the direction of flow is from northeast to southwest. The distribution of underground river flow around the Bleri Cave with resistivity values around the Lowo Cave ranges from 61 Ωm - 550 Ωm, in the area around the Lowo cave there are no underground anomaly caves that are not drained by water. If you want to exploit underground river water it should be done in the area around Bleri Cave.

1. Introduction

Based on BPBD data from Blitar Regency, Kaligambir Village, Panggungrejo Subdistrict is an area that experiences drought during the dry season. Geologically the village is composed of limestone and coralline limestone. Groundwater flow in the limestone areas through gaps, fractures, and dissolving channels whose dimensions and directions are erratic. If the dimensions and direction of the river flow are known, it will be easier to exploit water to meet the needs of the community.

Before exploiting underground water, it is better to explore the potential of underground water. With the existence of information on the potential of Groundwater river, groundwater exploitation planning will go well. Mapping the potential of underground water can be done using the Very Low Frequency - Electromagnetic (VLF-EM) method. In this study, VLF-EM will be used to obtain the dimensions and direction of the underground river flow around Bleri Cave and Lowo Cave.

To get better VLF-EM data processing results, noise-assisted multivariate empirical mode decomposition (NA-MEMD) filtering is used before the inversion process is carried out using inv2DVLF.

2. VLF-EM method

Very low frequency-electromagnetic waves (Very Low Frequency 15kHz - 25 kHz) can penetrate the earth, travel through the air, reflect the ionosphere and can be released by the ionosphere to be displayed in space. With this capability, a very low frequency-electro magnetic wave transmitter was built and applied for military purposes related to submarine navigation. Only a few stations transmit electromagnetic waves that are very low. Although originally used for military purposes, the use of VLF waves was developed by geophysical scientists so that it can be used to study subsurface structures.

At a considerable distance from the transmitting antenna, the component of HP's primary electromagnetic field with very low frequency (VLF) can be considered a wave traveling horizontally. If below the surface there is a conductive medium, then the magnetic field component of the HP primary electromagentic wave will induce the medium so that it will induce an Eddy current, the Eddy current will produce a secondary magnetic field (Hs) which has a horizontal Hy component and a vertical component Hz.

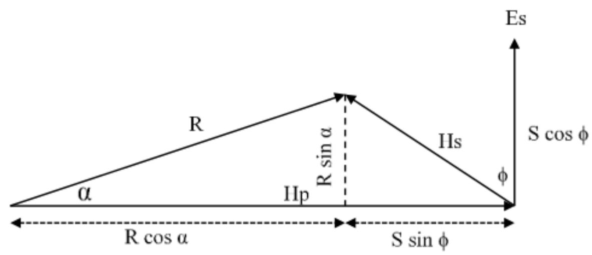

Figure 1. Primary and secondary field relationships

When the primary VLF wave enters the medium, ES induction electromotive force (emf) will appear with the same frequency, but the phase lags behind 90º. Figure 1 shows a vector diagram between the HP primary field and the Ice induction emf. The combination of HP and HS will form a resultant R which is in phase with the HP component (Rcosα) called the real component (inphase) and the component perpendicular to HP (Rsinα) is called the imaginary component (out-of phase / quadrature). The comparison between real and imaginary components is expressed in the equation :

$$\frac{Re}{Im} = \tan\phi = \omega\frac{L}{R} \quad (1)$$

With :
- Re = Real Component
- Im = Imaginary Component
- ϕ = Phase difference (º)
- ω = Field angular frequency
- L = Inductance
- R = Resistivity

The equation above shows that if the greater the Re / Im ratio, the greater the phase angle, the better the conductor, and vice versa if the smaller the Re / Im ratio, the smaller the phase angle, the worse the conductor will be. As the illustration illustrated in Figure 2, contact areas that have different resistivity values will produce an VLF anomaly that is indicated by inphase and quadrature curves.

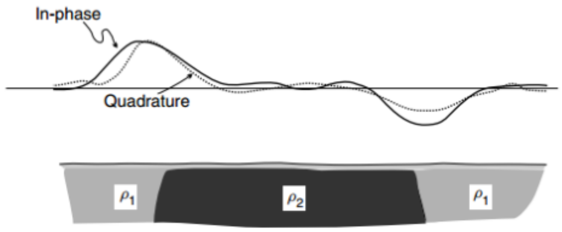

Figure 2. VLF magnetic field anomaly in 2 mediums

VLF-EM (inphase and quadrature) data acquisition is usually poor due to highly non-stationary noise. This noise can create biases that affect VLF-EM data, making the data difficult to interpret and to be further analyzed, both qualitatively and quantitatively. Thus, robust filtering method is needed to improve and enhance the VLF-EM data quality. A robust method is NA-MEMD. This method is used to improve VLF-EM data for identification of underground rivers in karst areas. NA-MEMD is applied to simultaneously decompose tripper data to produce IMF and residues. The IMF selected from both data sets became the filter bank for reconstruction. The reconstructed VLF-EM data was greatly enhanced and the data made easier to process through qualitative and quantitative analysis. The details of the NA-EMD method to decompose bivariate VLF-EM data are as listed below :

a) Create several channels of uncorrelated Gaussian white noise time-series (mchannel) with the same length as that of the input.
b) Add the noise channels created in step "a)" to the bivariate VLF-EM data (2-channel) signal, obtaining (2 + m)-channel signal, y =[In-phase Quadrature Noise]^T.
c) Process the resulting (2 + m)-channel multivariate signal using the MEMD algorithm to obtain multivariate IMFs.
d) From the resulting (2+m)-variate IMFs, exclude the *m* channels corresponding to the noise, giving a set of 2-channel IMFs corresponding to the bivariate VLF-EM data.

3. Methodology

3.1. Data acquisition

The VLF-EM measurement area is devoted to two hamlets in the village of Kaligambir which have underground river potential. the first hamlet is Panggungpucung which has a Bleri cave, in this cave there is an underground river flow but the flow is unknown. The second village is Kedungbulus which has Lowo cave. VLF-EM data collection was carried out on 18 trajectories spread across two study areas. Each VLF-EM track has a track length of 200 meters, data collection is done at intervals of 2 meters. Measurement of VLF-EM yields 101 datums. The track design can be seen in Figure 3. The making of the track uses the GPS geodetic RTK method so that the shape of the track matches the design that was created..

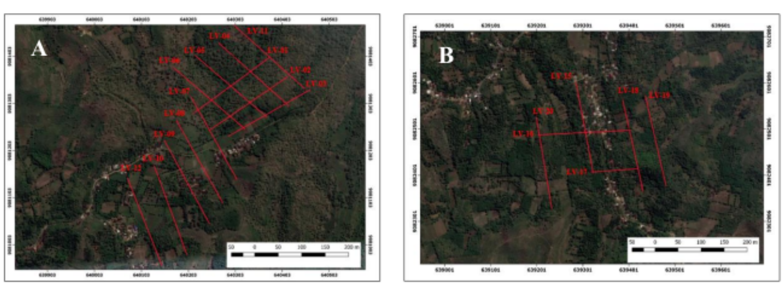

Figure 3. A. VLF-EM Lines in Bleri cave; B. VLF-EM lines in Lowo cave

3.2. *Data processing*

The data processing sequence can be seen in Figure 4. The data set obtained at the time of data acquisition was only partially taken, namely inphase and quadrature data. In the data processing, there are two jobs that must be done. The first work is filing inphase and quadrature data. Filtering uses noise-assisted multivariate empirical mode decomposition (NA-MEMD) which aims to eliminate non-linear noise from VLF-EM itself. Using this filter can improve quality and eliminate noise from inphase and quadrature.

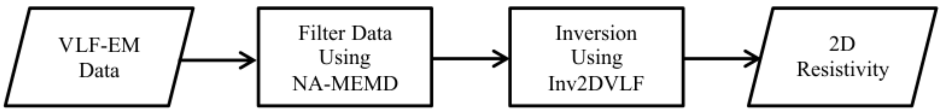

Figure 4. data processing sequence

the second step is to reverse filtered inphase and quadrature data. Inversion is a mathematical translation to get information about a physical system based on observational data on a system. The inversion process is done using Inv2DVLF software based on the Finite Element Method, this software was developed by Monterio Santos. The result of this inversion process is the distribution of resistivity values along the VLF path at each depth.

4. Result and discussion

4.1. *Bleri cave*

The results of VLF-EM data processing around Bleri Cave can be seen in Figure 5. The range of resistivity values around Bleri Cave ranges from 53 Ωm - 685 Ωm. Underground river anomalies were found on 6 VLF-EM lines (LV-01, 03, 05, 06, 09, 11). Groundwater river is found at a depth of 40 meters from the ground surface. Groundwater exploitation can be carried out on 6 tracks that have underground river anomalies, for the coordinates of the exploitation point can be seen in Table 1.

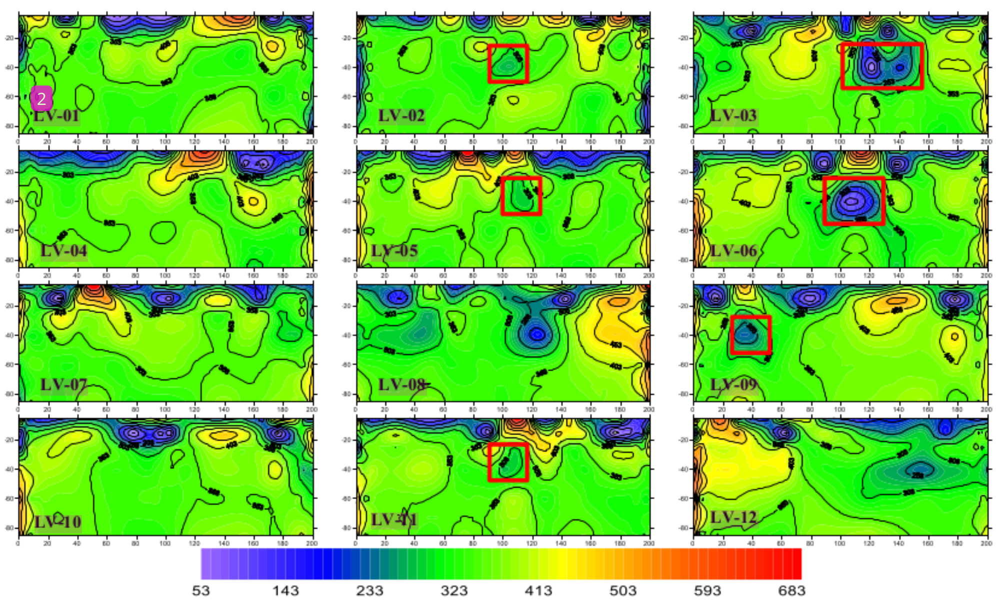

Figure 5. Groundwater river patterns around Bleri cave

Table 1. Underground river exploitation coordinates

Code	Coordinate (49 S Zone)	
	X	Y
LV-02	640331.37	9081303.34
LV-03	640356.62	9081273.24
LV-05	640294.62	9081338.93
LV-06	640254.80	9081307.79
LV-09	640171.35	9081189.18
LV-11	640377.82	9081396.51

Figure 6 shows the distribution of the underground river flow in the Bleri cave, the underground river flows from the northeast to the southwest, on the LV-5 there is a branching of the underground river flow to the south.

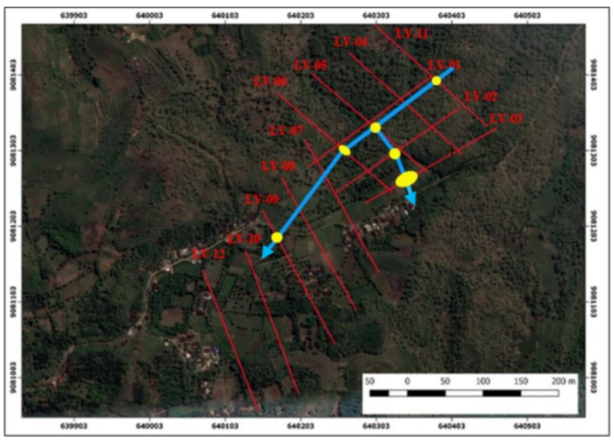

Figure 6. Distribution of the underground river flow in the Bleri cave.

4.2. Lowo cave

The results of VLF-EM data processing around Lowo Cave can be seen in Figure 6. The range of resistivity values around Lowo Cave ranges from 61 Ωm - 550 Ωm. No underground river anomalies were found in the study area around Lowo Cave.

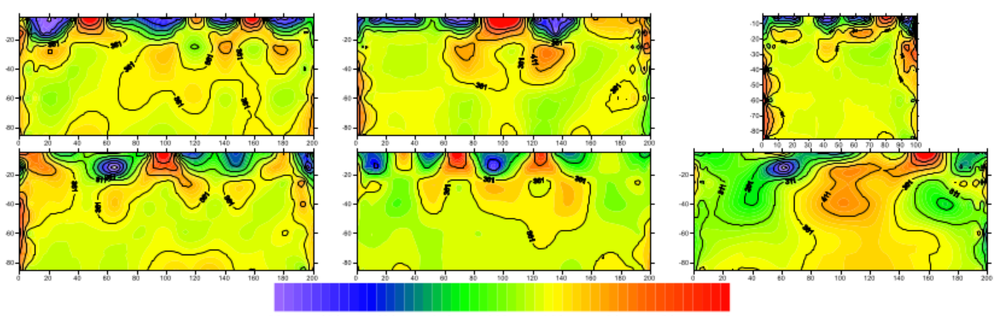

Figure 6. Groundwater river pattern around Lowo cave

5. Conclusion

The result of VLF-EM data processing is the distribution of resistivity values around Bleri caves (53 Ωm - 685 Ωm) and Lowo caves (61 Ωm – 550 Ωm). From the interpretation of VLF-EM data around the Bleri cave, it was found that there were 6 locations of underground rivers with a depth of 40 meters. exploitation of underground river water can be carried out in these 6 locations. In the area around the Lowo cave, no underground river anomalies were found.

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