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Identification of Underground River Flow Using VLF (Very Low Frequency) and Geoelectricity at Karstic Area

Mahmuddin Marbun*
Department of Mechanical Engineering,
Universitas Teuku Umar,
INDONESIA

Sismanto
Department of Physics,
Gadjah Mada University,
INDONESIA

Zuhrahmi DE
Department of Interior Design,
Institut Seni Budaya Indonesia
INDONESIA

Imran Tarique
Atta Ur Rehman School of Applied Biosciences,
National University of Science and Technology,
PAKISTAN

Punhoon Khan Korai
Lasbela University of Agriculture Water and
Marine Sciences, Uthal Balochistan,
PAKISTAN

***Correspondence: E-mail:** mahmudin.marbun@utu.ac.id

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Abstract

Mapping underground river karst areas in the karst mountains Cianjur, West Java, has been done using electromagnetic methods and Geoelectricity Dipole-dipole. Karst constituent formation region of West Java area is limestone, clay stone, limestone fractured, hard and dense limestone, and limestone containing no water (rigid). The aim of this research is to search for the existence of underground rivers using electromagnetic and geoelectric wave surveys. VLF method consists of 13 line with a length of 750 m and a 10 m spacing. Based on the results of data processing VLF method is known that the equivalent current density (ECD) demonstrated high conductive rocks. While Geoelectricity method consists of 10 line, the arrangement is a parallel between the distance of the line with a space of 20 m andlength between 300 m. VLF data interpretation results indicate anomalous equivalent current density (ECD) with high scores range from 180-300% indicated fractured limestones are occupied by water, while the resistivity anomaly from 0.45 to 7.40 Ω.m indicated as weathered limestone layers accumulated dengn clay stone, resistivity values 186-701 Ω.m, fractured limestones indicated that fills with water. With sizes ranging 5-15 m cavity, each line with nearly the same distance at a depth of approximately 15-105 m, there is a large cavity-cavity interconnected.

Keywords: resistivity; conductivity; limestone; fractured limestones; underground river

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INTRODUCTION

Karst morphology West Java in mountain region is hilly limestone with a very wide stretch of karst. Geological processes in the karst region is formed of carbonate soluble and react in water especially acidic water. Karst is an area with special conditions as a result of rock-soluble and has a well-developed secondary porosity (MOE et al., 2016). Then followed by their dissolution and the gap as the water flows. Dissolution of limestone by rainwater causing small holes which then extends entrance down the ground formed a sinkhole area karts which is not possible to accommodate water in the surface, because the nature of the limestone porous and immediately pass the rainwater that falls on the ground past the fracture rock. Water that passes will flow beneath the surface, accumulate and form a certain pattern of flows through the halls of the cave becomes an underground river (Adji et al., 2017; Haryono et al., 2016).

Geological research method directly gives less widely mapping the direction and type of karst structures. Although some outcrops appear, research on surface directly provides less information on the layer thickness and distribution of karst fracture is usually associated with karst water system. The geophysical survey can help complete this problem. Considering the uniqueness and diversity of karst natural, geophysical methods applied in search of water, karst must meet certain criteria. Those methods should be sufficiently high resolution at shallow depths with rapid data acquisition for a fairly wide area. Applied geophysics research on Karst Hydrogeology of aquifers emphasized on electromagnetic method that meet the secriteria (Haryono et al., 2016).

There are two methods that are very suitable for detecting the presence of groundwater in areas that have very high differences in conductivity, they are 1). the VLF method takes advantage of the wave (carrier wave) of a transmitter made by the military actually used for communication and navigation of submarine. These waves have penetrated deep enough for a fairly low frequency. VLF waves spread throughout the world with a small attenuation in the waveguide between the earth's surface and the ionosphere. Since the induction of the primary wave, in a conductive medium will arise induced currents (Eddy current). This induced current generating a secondary field can be captured on the surface. The amount of secondary EM field strength is proportional to the magnitude (σ), so by measuring the field of electrical conductivity of rocks strength in a particular direction, indirectly in the detection of electrical conductivity of rocks underneath. Measurement of conductivity and dielectric constant of the earth by using wave tilt technique was first performed in 1930 (Haryono et al., 2016). This initial measurement is carried out at relatively high frequency so that the penetration depth of the resulting shallow (Al-ahmadi & El-Fiky, 2009; Tsunomori et al., 2017) using the signals emitted by the broadcasting station to conduct geological mapping. This method is known as a method of radio waves (the radio wave method) (Al-ahmadi & El-Fiky, 2009; Tsunomori et al., 2017). VLF-EM method chosen to investigate underground rivers in karst areas for a significant resistivity contrast. Underground river in the medium limestone closely related to cracks and crevices which uniquely widened because of the dissolution process. The appearance is often filled by a fluid such as water which implies varied, thus increasing the electrical conductivity significantly than karst environment itself and make it easily detectable by EM techniques such as VLF-EM (Al Bulushi et al., 2016; Karous, M. and Hjelt, 1983; Khalil & Santos, 2011). Use of VLF also allows to detect, describe the structure of the variation of karst widely and estimate interconnect lines in karst which is usually occupied by water or clay sediments. During this processing and data modeling VLF still has limitations, especially in its interpretation. Acquisition of data relatively easily although the terrain is quite heavy, so the VLF electromagnetic method is promising for use in mapping undergroun drivers and Geotechnical. 2). Method of Dipole-Dipole Geoelectricity only as supporting data and comparative research underground river. Geoelectricity method in use is the dipole-dipole configuration. This method is based on the circumstances that caused when electric current is applied to the soil through the electrodes, in a medium conductivity changes. The magnitude of this influence on surface potential is influenced by the size, location, shape and conductivity of the material below the earth's surface. In this way, information about subsurface distribution will be obtained by measuring the electrical potential on the surface.

METHOD

This study uses VLF and Geoelectricity Configuration Dipole - dipole. This study was conducted from September 2015 to complete the Geophysical Laboratory at the Department of Physics, Faculty of Mathematics and Natural Sciences University of Gadjah Mada. Research Areas Located in the district of Cianjur, West Java mountain Karst shown in **Figure 1** which is a mountainous area with a carpet of limestone very broad so as to allow the occurrence of cavities in underground surface, called the Cave.

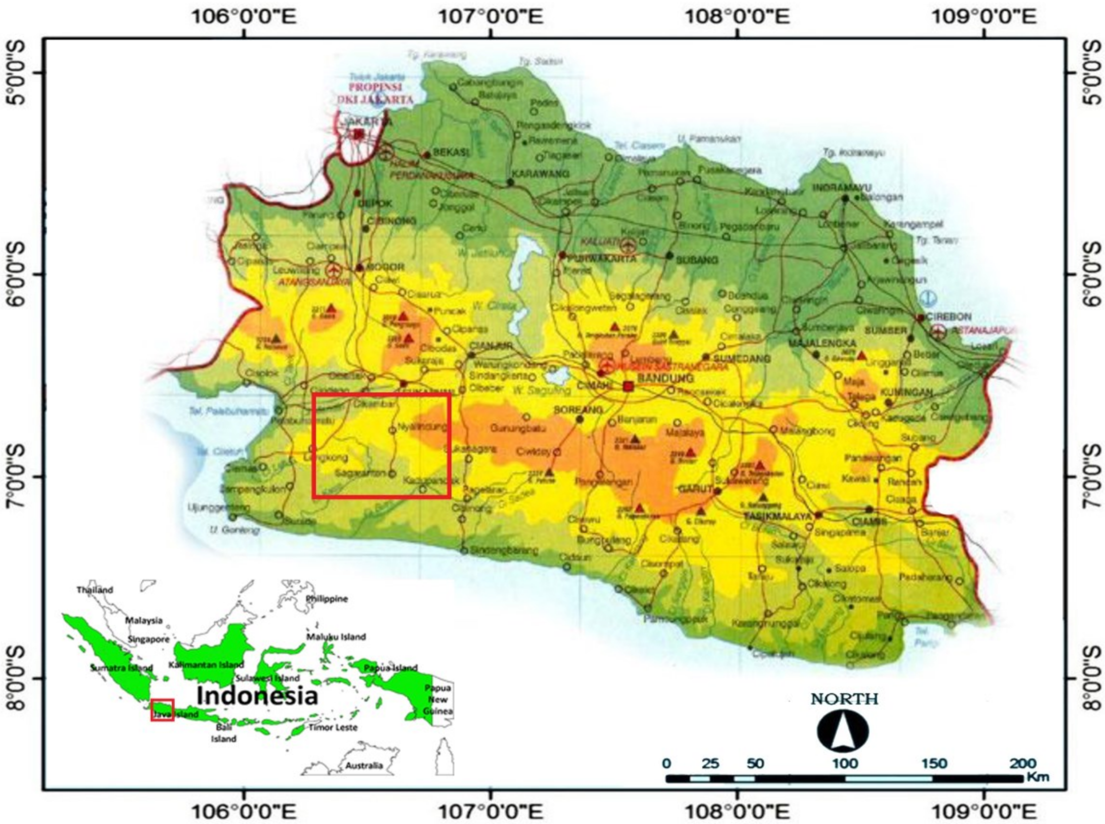

Figure 1. Map of location

Acquisition of data held from September 15 to October 2, 2015. 4.1 Field Data Acquisition and Design Survey The data obtained were then processed. Using secondary data, VLF many as 13 line and Geoelectricity Configuration Dipole - dipole, as many as 10 line, with a target seeking cavity a cavity filled with water and the continuity of the cavity, as an underground river in **Figure 2**.

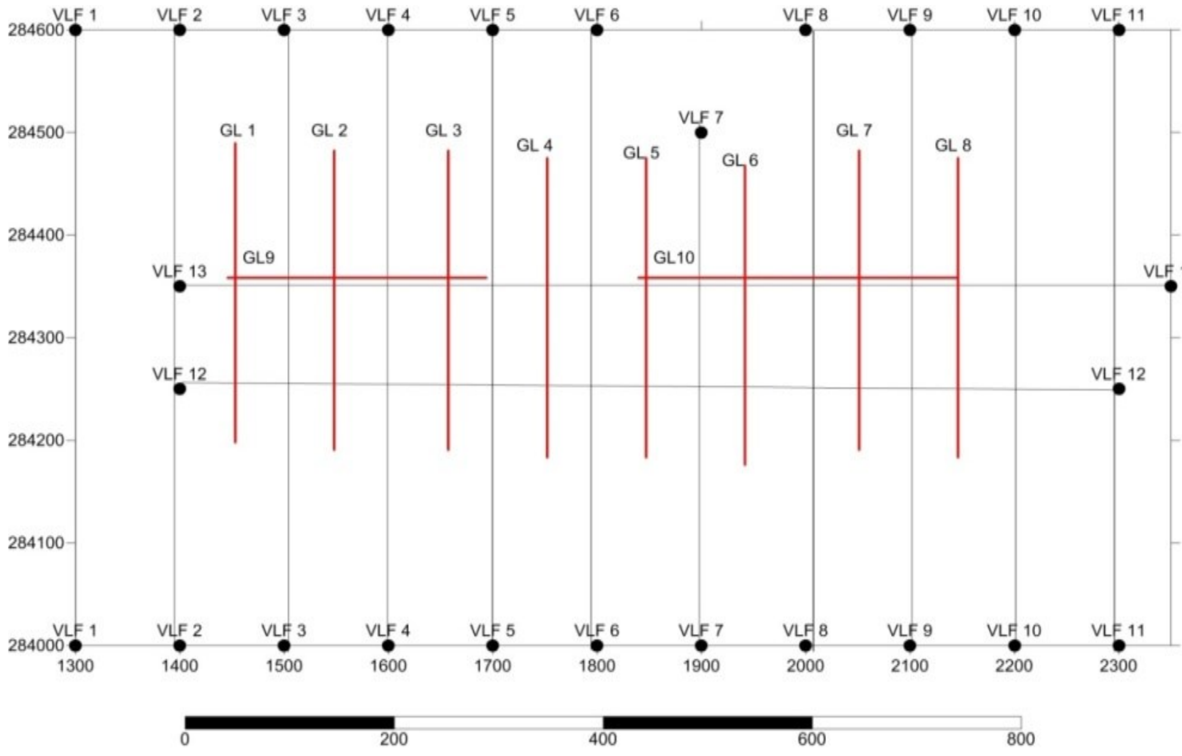

Figure 2. VLF Survey design and configuration geoelectricity dipole – dipole

RESULTS AND DISCUSSION

The secondary data obtained is data on current strength, potential difference, electrode spacing. This research was carried out in the karst mountain area of West Java, Cianjur Regency. This geoelectric research consists of 10 lines. The line arrangement is parallel with a distance between the lines with a spacing of 20 meters and the stretch on each line is between 300 meters. The data is then processed to obtain resistivity values for each measurement line.

The data obtained is in the form of resistivity values from each measurement line so as to obtain actual information from below the surface. The results of the cross-sectional interpretation are images with different colors, where each color represents the resistivity value. The color difference that appears is a difference in the resistivity value. Then it is interpreted and matched with the geological information of the research area. The topography visible in 2D cross-section increases the accuracy of determining the position and depth of the research target. So the position and depth in the 2D cross section are the actual conditions in the field.

This VLF method consists of 13 lines with a line length of 750 meters and a spacing of 15 meters. Based on the results of the VLF method data processing, it is known that a high equivalent current density (ECD) value indicates that the rock is conductive, reflecting the ability of the object or rock to conduct a magnetic field so that it can be expressed in terms of conductivity. In the area under scrutiny, high conductivity enclosures are interpreted as areas or rocks that have or contain water. The results of this VLF processing support geoelectric data which also shows regional patterns with interconnected water content. Equivalent current density is a physical quantity that can be related to the level of conductivity of a rock.

Geoelectric Data Analysis

The cross-sections generated from the RES2DINV software are then analyzed by looking at the resistivity values at each cross-section, and then compared with the resistivity values based on existing references (Baker & Myers, 1980). So from these cross-sections there is rock resistivity information indicating that there are anomalies below the surface of the research area which makes it possible that this is the target in this research. The results of the interpretation of the resistivity data are as follows:

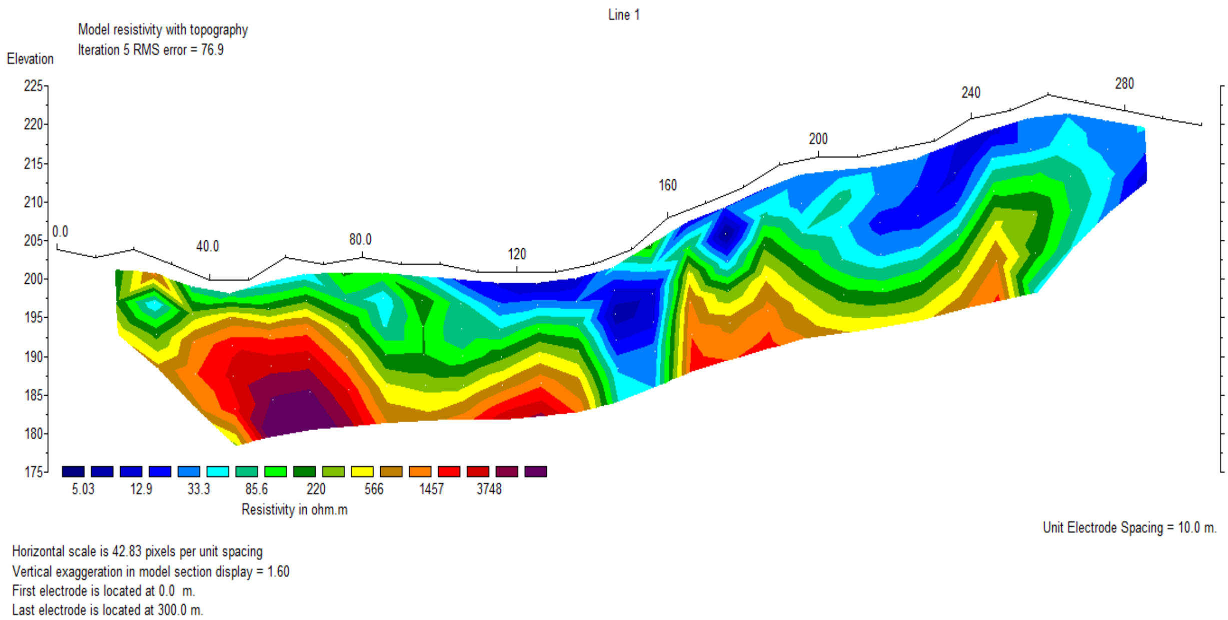

Figure 3. 2D Geoelectric Dipole-dipole cross section

Figure 3 is an interpreted cross-section with several color gradations representing different geological phenomena. The color gradation of blue to green with a value range of (85.6 – 566) ohm meters is interpreted as mudstone lensing the limestone in the middle of the cross section. The yellow to purple color gradation with a resistivity value range of (1457 – 3748) ohm m is interpreted as very dense or hard limestone.

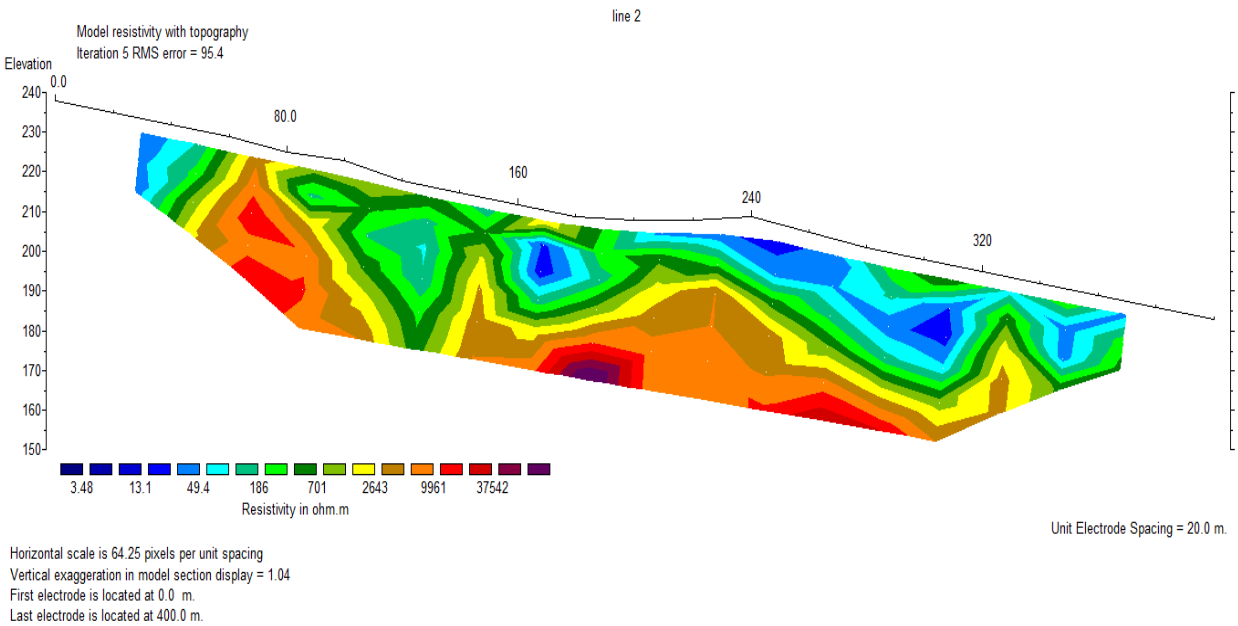

Figure 4. Dipole-dipole Geoelectric 2D Cross Section

Figure 4 is the second line which is interpreted with several color gradations which have a resistivity value range of (3.48 – 48.3) ohm meters as soil. The color gradation of blue to green with a value range of (186 – 701) ohm meters, is interpreted as mudstone lensing the limestone, found in the middle of the cross section. The yellow to purple color gradation with a resistivity value range of (2643 – 37543) ohm m, is interpreted as very dense or hard limestone, so that electric current cannot penetrate the rock and results in a large resistivity value (Fraser, 1969).

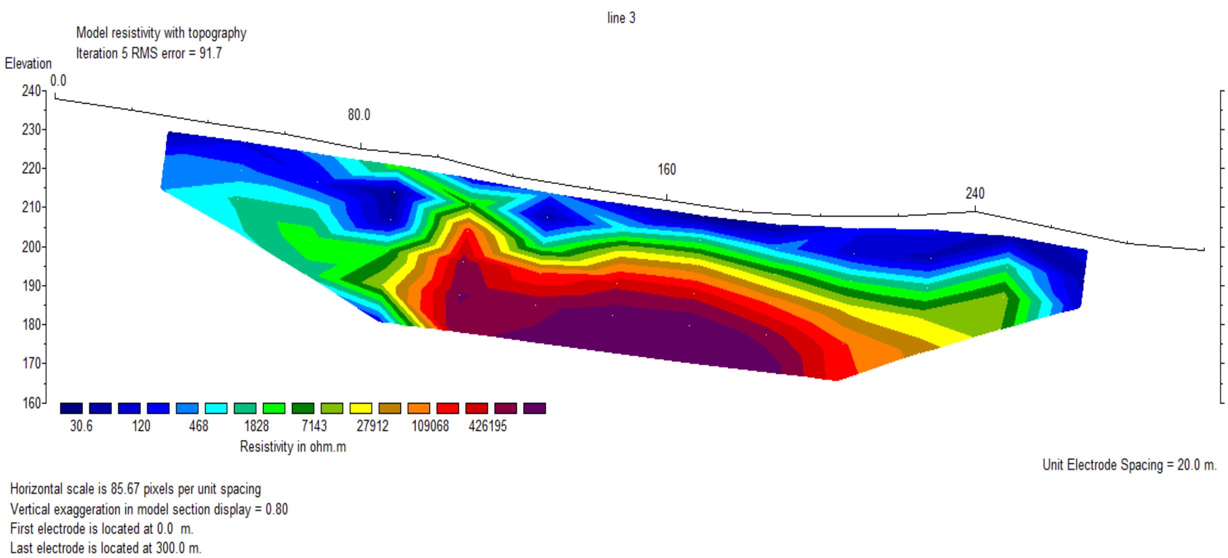

Figure 5. Dipole-dipole Geoelectric 2D Cross Section

Interpretation of **Figure 5** shows that several gradations of yellow to purple with a resistivity value range of (27921 – 4261955) ohm meters, as very dense or hard limestone.

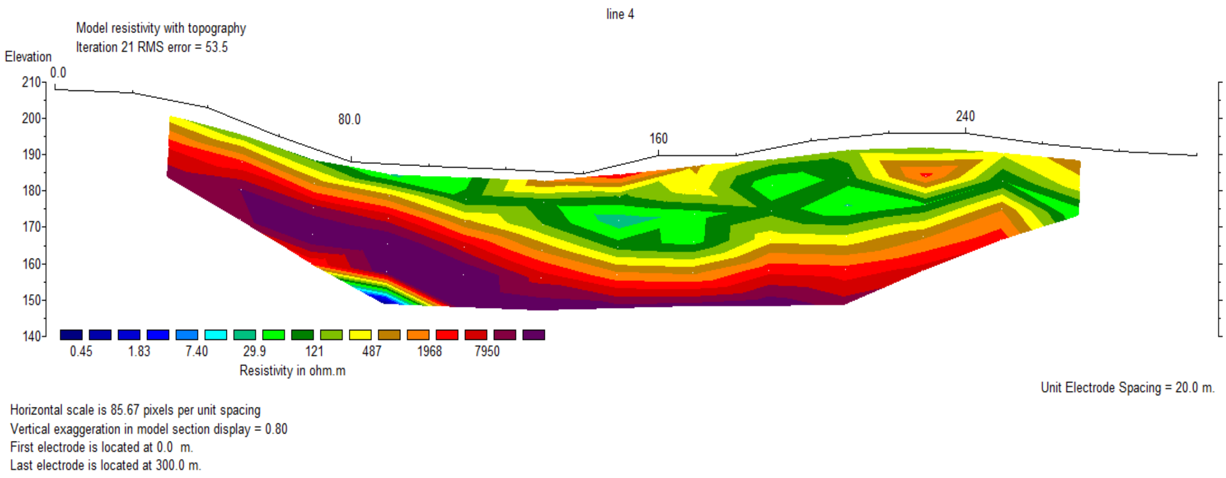

Figure 6. Dipole-dipole Geoelectric 2D Cross Section

Interpretation of **Figure 6** shows that several gradations of dark blue-blue have a resistivity value range of (0.45 – 7.40) ohm meters as soil. The color gradation is yellow to purple with a resistivity value range of (487 – 7950) ohm m, as limestone is very dense or hard, so that electric current cannot penetrate the rock and results in a large resistivity value.

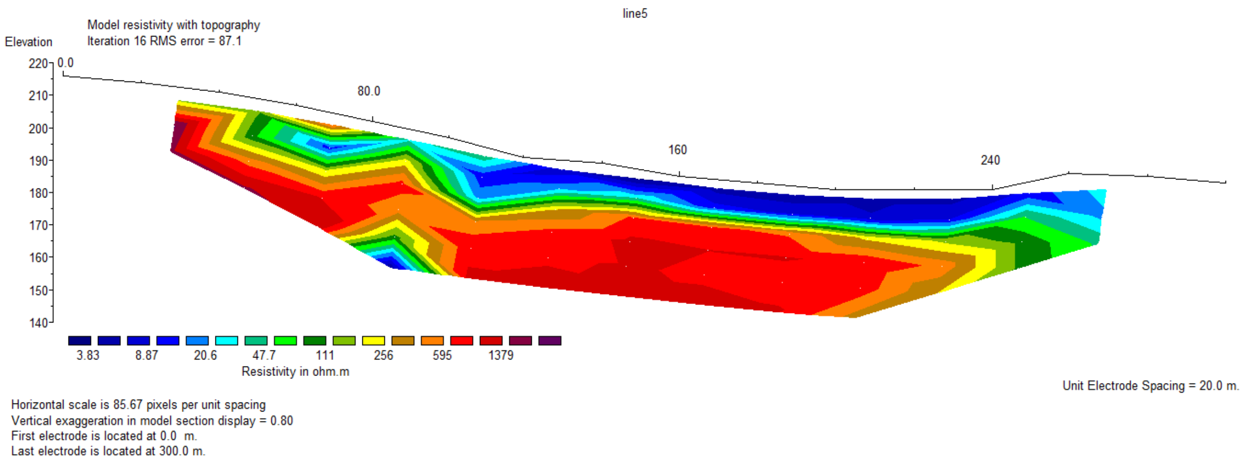

Figure 7. Dipole-dipole Geoelectric 2D Cross Section

Interpretation **Figure 7** is interpreted with several gradations of yellow to purple with a resistivity value range of (256 – 1379) ohm m, as very dense or hard limestone.

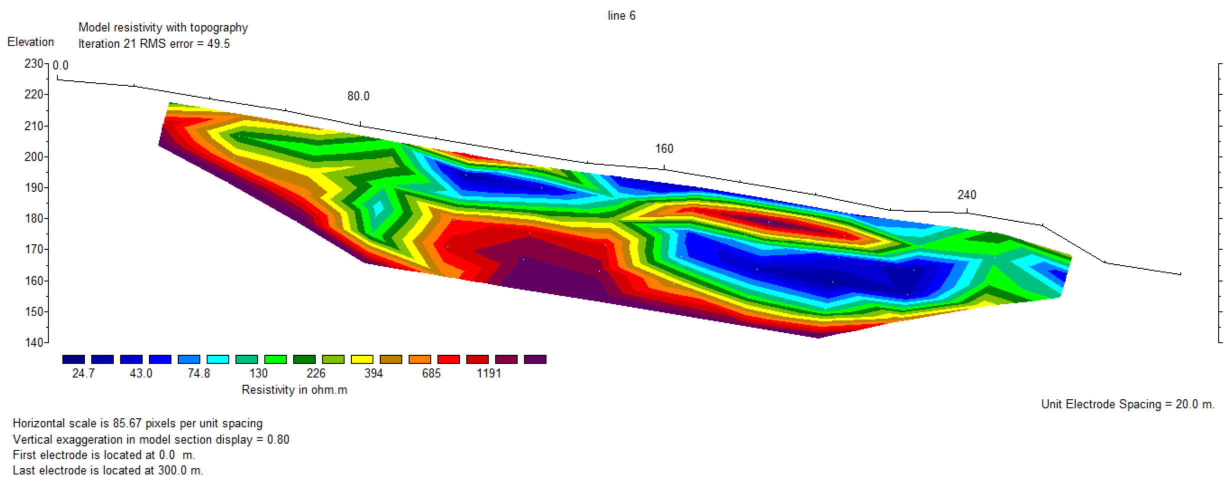

Figure 8. Dipole-dipole Geoelectric 2D Cross Section

Interpretation of **Figure 8** shows a cross-section of blue to green color gradations with a value range of (74.8 – 130) ohms interpreted as mudstone lensing on limestone in the middle of the cross-section, yellow to purple color gradations with a resistivity value range of (394 – 1191) ohm m , as hard and dense limestone.

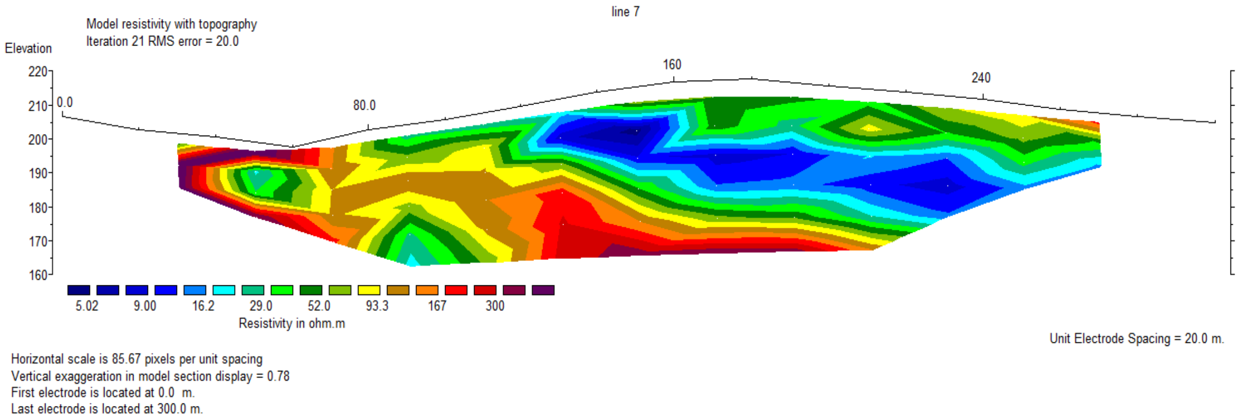

Figure 9. Dipole-dipole Geoelectric 2D Cross Section

Interpretation of **Figure 9** shows that several color gradations with a resistivity value range of (5.02 – 9.00) ohm meters are soil, blue to green color gradations with a value range of (16.2 – 52.0) ohm are interpreted as claystone which Melens in limestone is found in cross-section, the color gradation is yellow to purple with a resistivity value range of (93.3 – 300) ohm m which is interpreted as very dense or hard limestone (Saha et al., 2019).

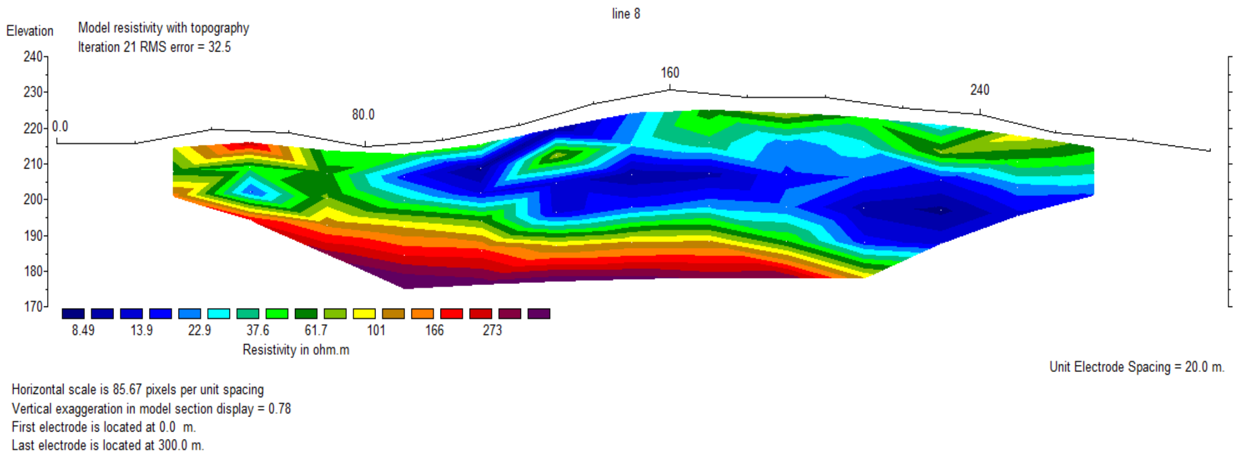

Figure 10. 2D Geoelectric Dipole-dipole cross section

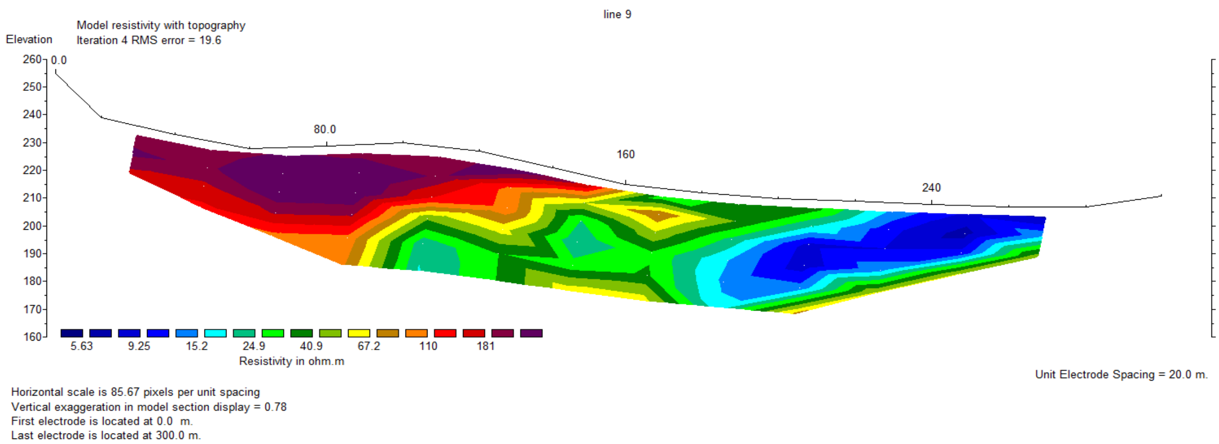

Figure 11. Dipole-dipole Geoelectric 2D Cross Section

Interpretation of **Figure 10** shows that several gradations of blue to green with a value range of (22.9 – 61.7) ohms are interpreted as mudstone lensing on limestone. Yellow to purple color gradations with a resistivity value range of (101 – 273) ohm m are stone limestone is hard and dense.

Interpretation of **Figure 11** shows that with a blue to green color gradient with a value range of (15.2 – 40.9) ohm m, it is interpreted as mudstone lensing the limestone in the middle of the cross section, while at the top it is interpreted as soil in line 10.

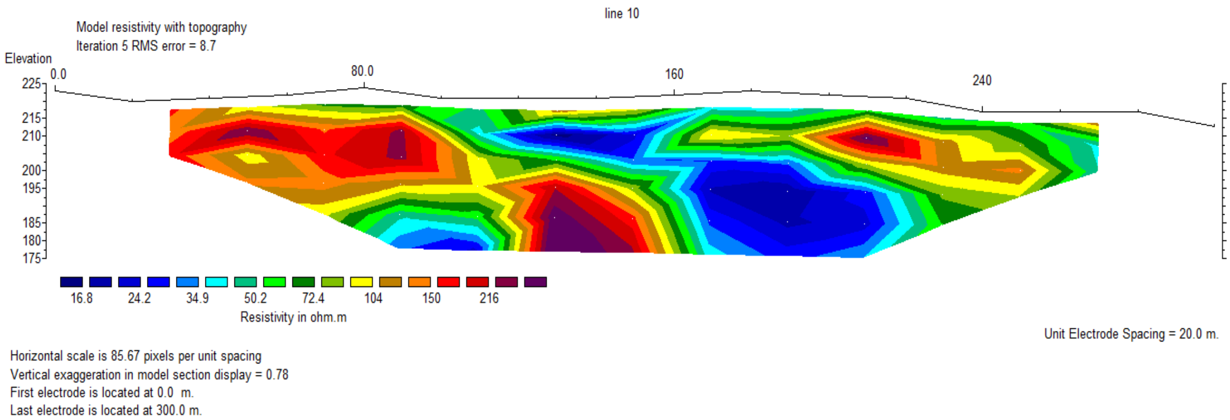

Figure 12. Dipole-dipole Geoelectric 2D Cross Section

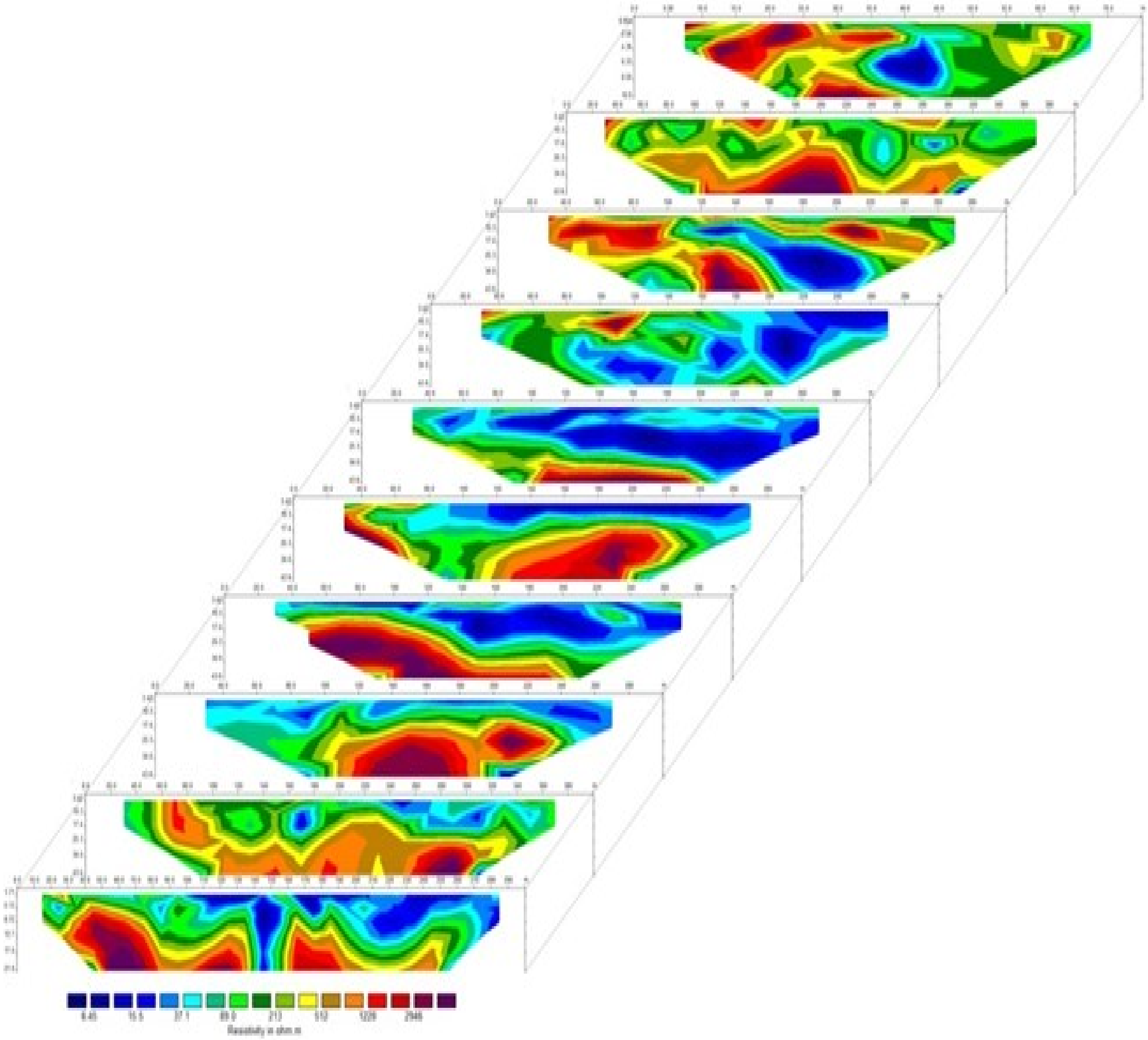

Figure 13. 2D Geoelectric Dipole-dipole Cross-Sections

Interpretation of **Figure 12** shows several gradations of blue to green with a value range of (34.9 – 72.4) ohm m, interpreted as clay stone lensing on limestone, yellow to purple color gradations with a resistivity value range of (104.2 – 216) ohm m, interpreted as very dense and hard limestone.

The cross-sections generated from the RES2DINV software are then analyzed by looking at the resistivity value at each cross-section, and then compared with the resistivity value based on existing references as in **Figure 13**.

The Geoelectric Method survey was carried out in parallel with the VLF Method, from the results of the geoelectric interpretation it did not find the existence of an underground river, which was due to the stretch of the line and its depth only reaching 30 meters. It can be seen from the interpretation that the resistivity value of 0.45 – 7.40 Ω.m is indicated as soil, resistivity 186 – 701 Ω.m is indicated by mudstone which is lensed in limestone, resistivity 3748-426195 Ω.m is indicated by hard and dense limestone.

VLF Data Processing and Analysis

Based on the results of the VLF method data processing, it is known that a high equivalent current density (ECD) value indicates that the rock is conductive, reflecting the ability of the object or rock to conduct a magnetic field so that it can be expressed in terms of conductivity. At a closer look, high conductivity enclosures are interpreted as areas or rocks that contain water.

There are several closure patterns that have high ECD values, the cross-section indicates the presence of objects that have good electrical conductivity. This high ECD value is caused by the presence of rocks that have large amounts of negative ions which contain water, but the interpretation obtained from the cross-section above is that the high ECD closure is due to the presence of material that has fine grains or weak zones in the rock (Aizebeokhai & Oyeyemi, 2015; Harlaux et al., 2017). These are the cross-sectional results and analysis of VLF data as follows:

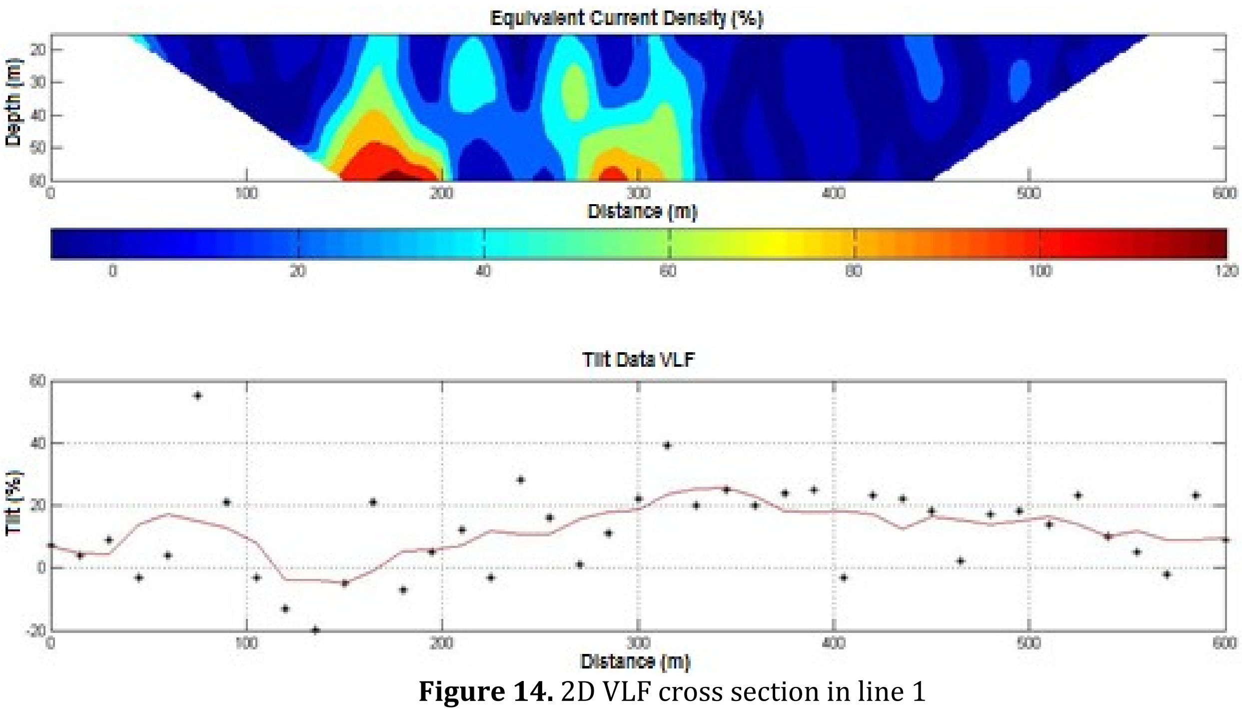

Figure 14. 2D VLF cross section in line 1

The cross-section of **Figure 14** is a cross-section of ECD which has blue to red color gradations, each gradation has a different range of conductivity values. The blue color gradation with a value range of (20 – 40)% is interpreted as hard limestone. The yellow to red color gradation which has a value range of (60 – 120)%, is interpreted as fractured limestone filled with water, thus forming cavities at a distance of 150-200 m, at a distance of 250-300 m.

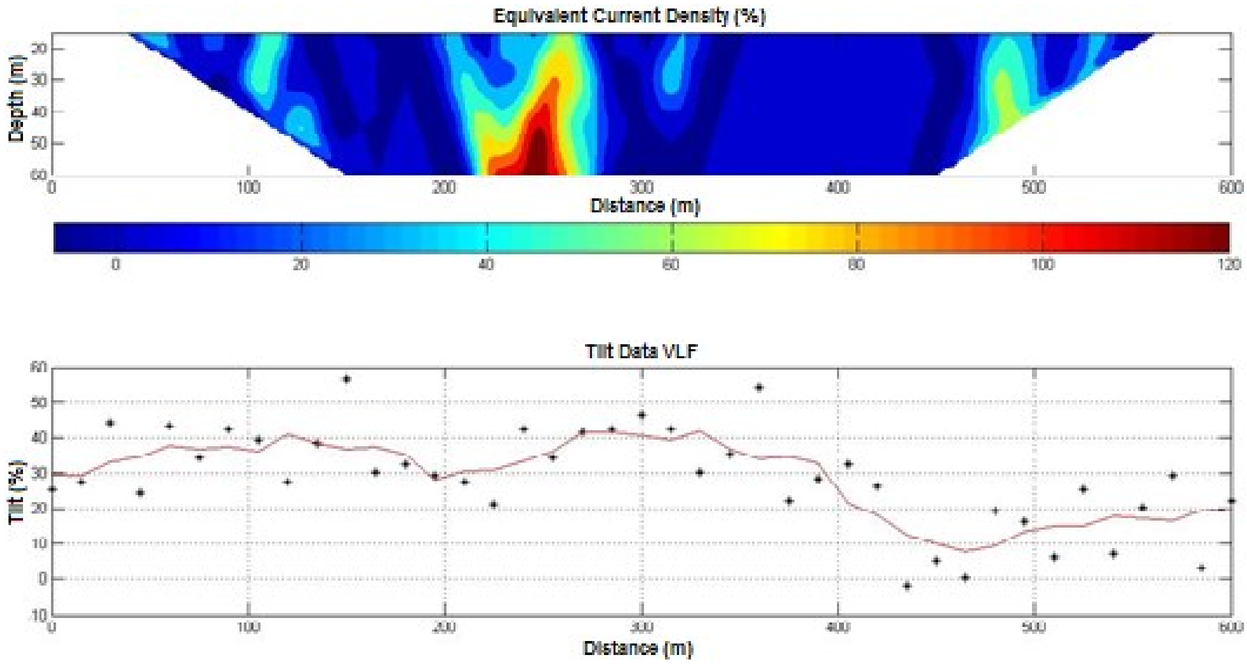

Figure 15. 2D VLF cross section in line 2

The cross-section in **Figure 15** is an ECD cross-section which describes the conductivity level of a rock. The blue color gradation with a value range of (10 – 30)% is interpreted as hard limestone. The yellow to red color gradation, which has a value range of (40-80)%, is interpreted as cavities in the limestone being fractured as a result of which cracks/voids appear in the fractured limestone, so that during the rainy season it can be filled with water and has a high conductivity value. The cavity is at a distance of 250 m, with a cavity size of 10-15 m, which is the assumed target underground river in this study.

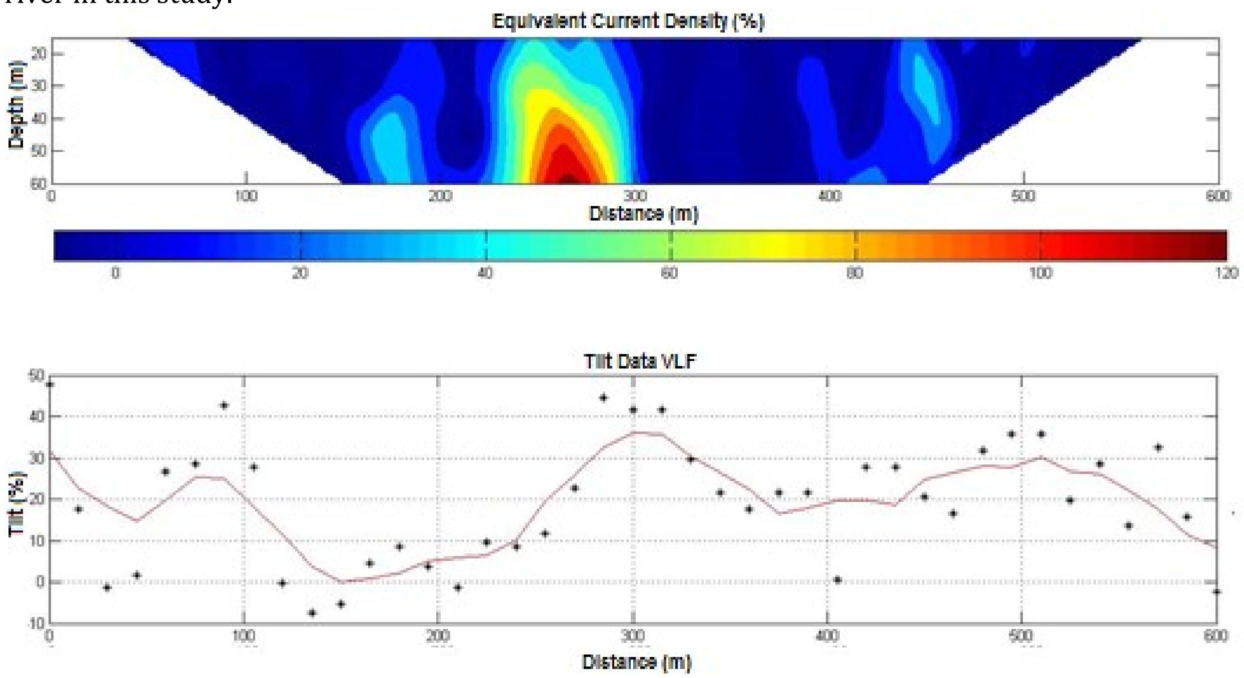

Figure 16. 2D VLF cross section in line 3

Figure 16 shows that the blue color gradation with a value range of (20-80)% is interpreted as hard limestone, while the yellow to red color gradation which has a value range of (100 – 200)% is interpreted as a cavity in the limestone filled with water so that it has a conductivity value. tall one. The graph below the cross section is a graph of the tilt values obtained from comparing the vertical and horizontal magnetic field components. This comparison of component values is used to produce the ECD cross section. The magnitude of the tilt value will be proportional to the ECD value, the cavity can be seen at a distance of 250 m, the size of the cavity is around 10-15 m.

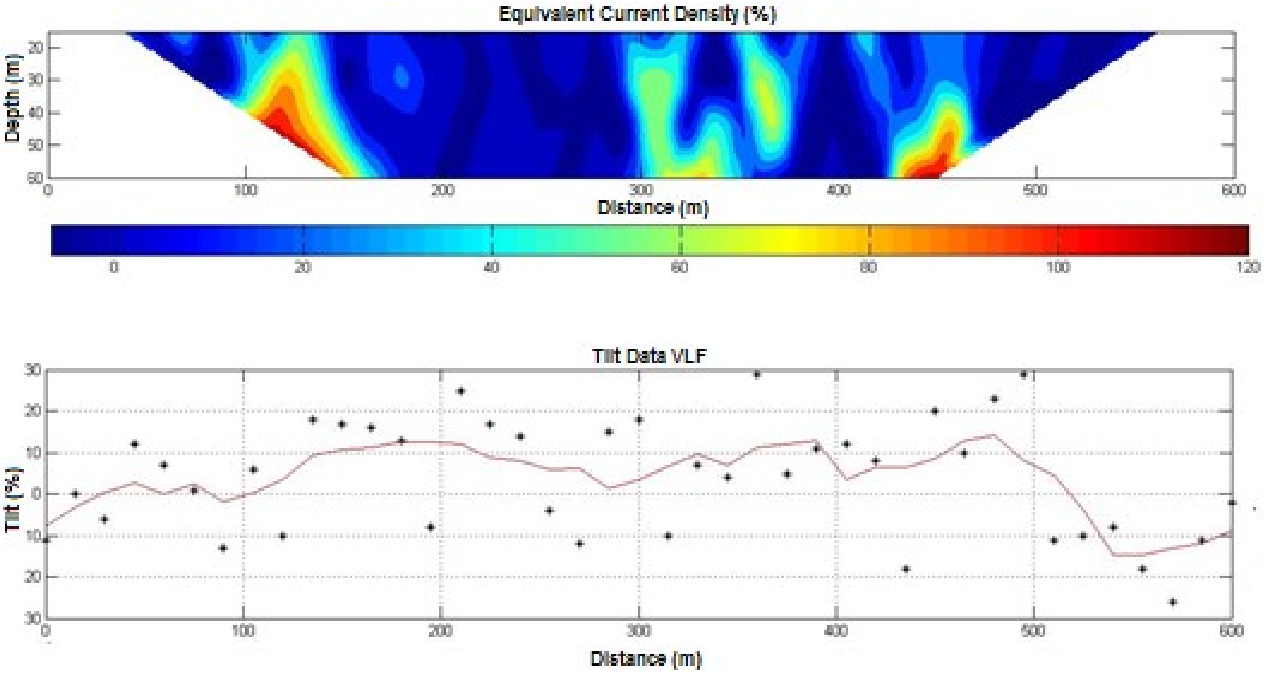

Figure 17. 2D VLF cross section in line 4

The cross section in **Figure 17** is an ECD cross section which has blue to red color gradations, each gradation has a different range of conductivity values. The blue color gradation with a value range of (10 – 40)% is interpreted as hard limestone. The yellow to red color gradation, which has a value range of (50 – 110)%, is interpreted as a cavity in the limestone that is filled with water so that it has a high conductivity value. In this research, the target is high conductivity values which are thought to be underground river flows in the form of karst land. In this cross-section there is a cavity about 10-15 m in size, at a distance of 100-150 m, at a distance of 450 m, a cavity is visible.

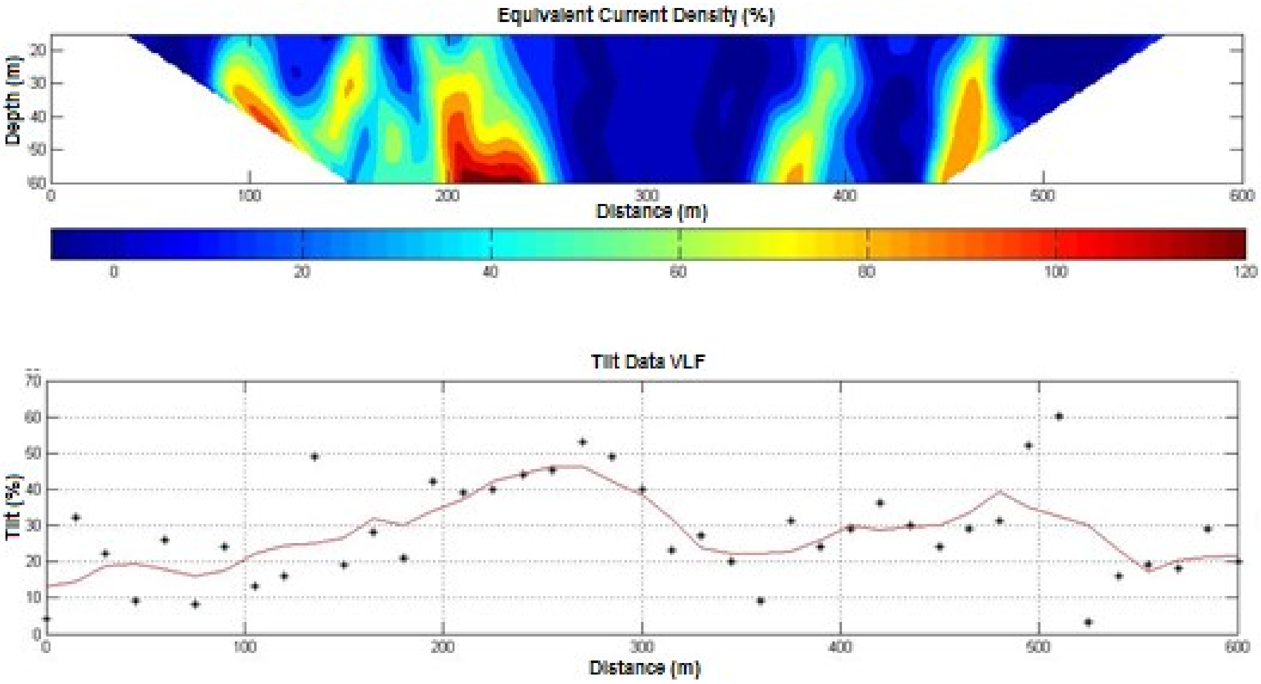

Figure 18. 2D VLF cross section in line 5

Interpretation of **Figure 18** cross-section, which has a blue color gradient with a value range of (10 - 50)%, is interpreted as hard limestone and a yellow to red color gradient which has a value range of (60 - 100)%, is interpreted as a cavity in the limestone which is filled with water so that it has a value high conductivity. It can be seen that on this line there is a continuous cavity at a distance of 100 m, the size of the cavity is around 10-20 m, at a distance of 200 m there is a cavity 10 m in size, at a distance of 450 m there is also a cavity that is around 10 m in size. In this research, the target is high conductivity values thought to be underground river flows.

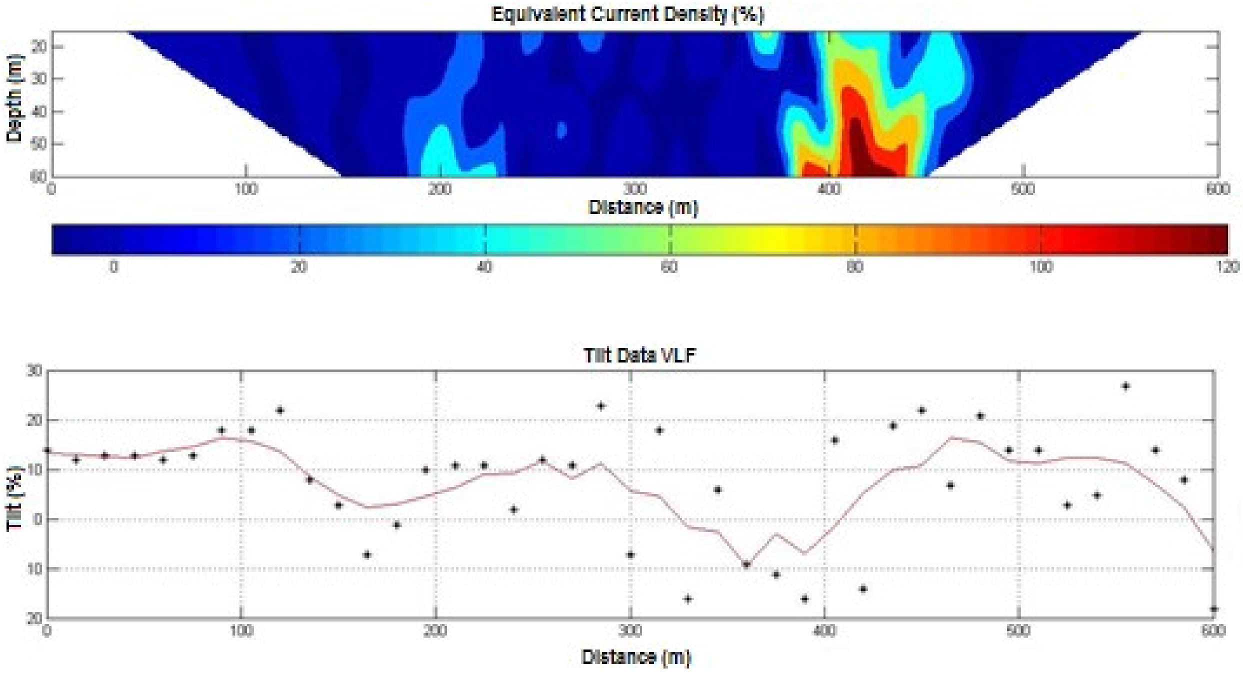

Figure 19. 2D VLF cross section in line 6

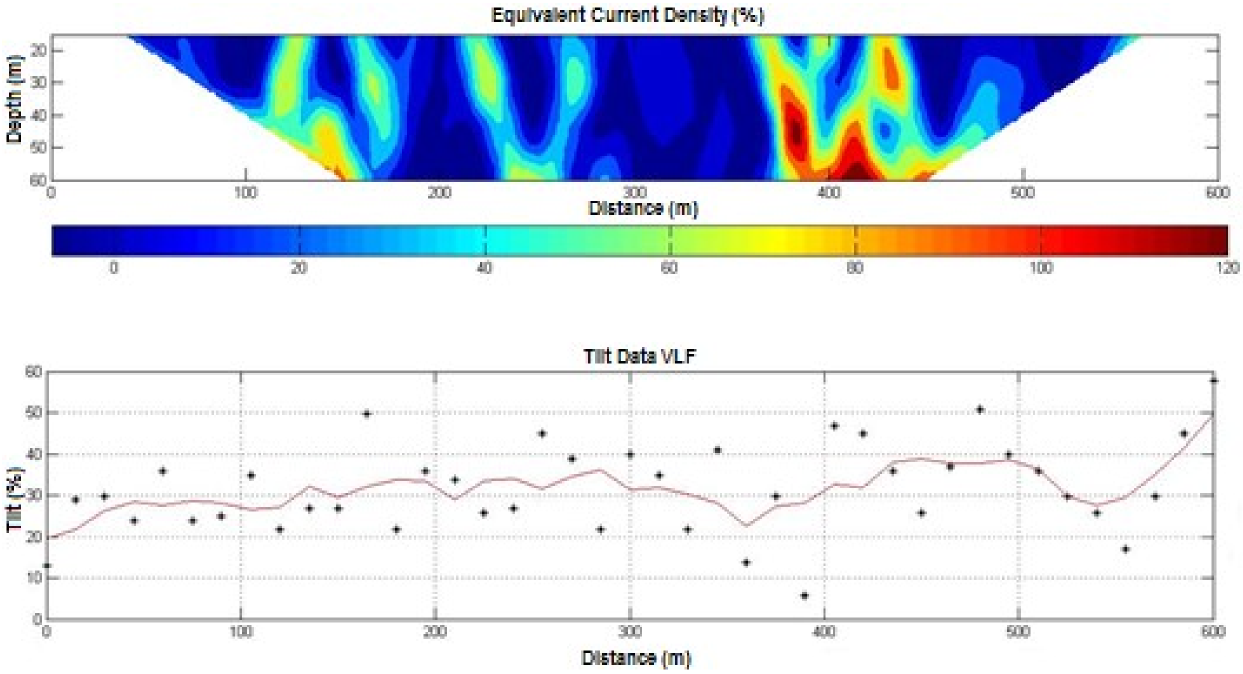

Figure 20. 2D VLF cross section in line 7

The interpretation of **Figure 19** is that there is a continuous zone of limestone fracture which is the main target for water to gather when the rainy season comes, so that water will break through the voids and will be eroded by the water. On this line there are voids at a distance of 400-450 m, with voids measuring around 10-15 m. The blue color gradation with a value range of (20-40)% is interpreted as hard limestone and is unable to conduct electromagnetic waves. The yellow to red color gradation which has a value range of (60-120)%, is interpreted as cavities in limestone filled with water so that it has a high conductivity value as the target in this research.

In **Figure 20**, the gradation of blue with a value range of (10 – 30)%, interpreted as hard limestone. The yellow to red color gradation with a value range of (40 – 80)% is interpreted as a cavity in the limestone that contains water as a target in searching for underground rivers. On this line there are cavities at a distance of 100-150 m, the size of the cavity is around 10-15 m, at a distance of 400-450 m, there is a continuous cavity with a cavity size of around 10-20 m.

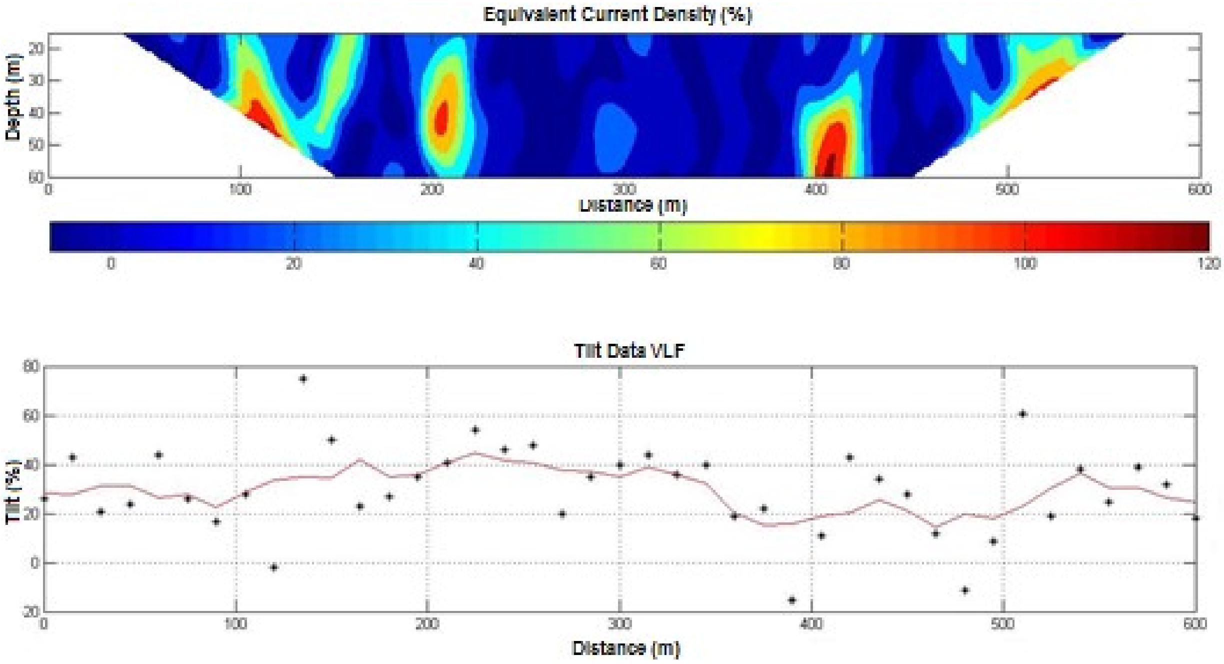

Figure 21. 2D VLF cross section in line 8

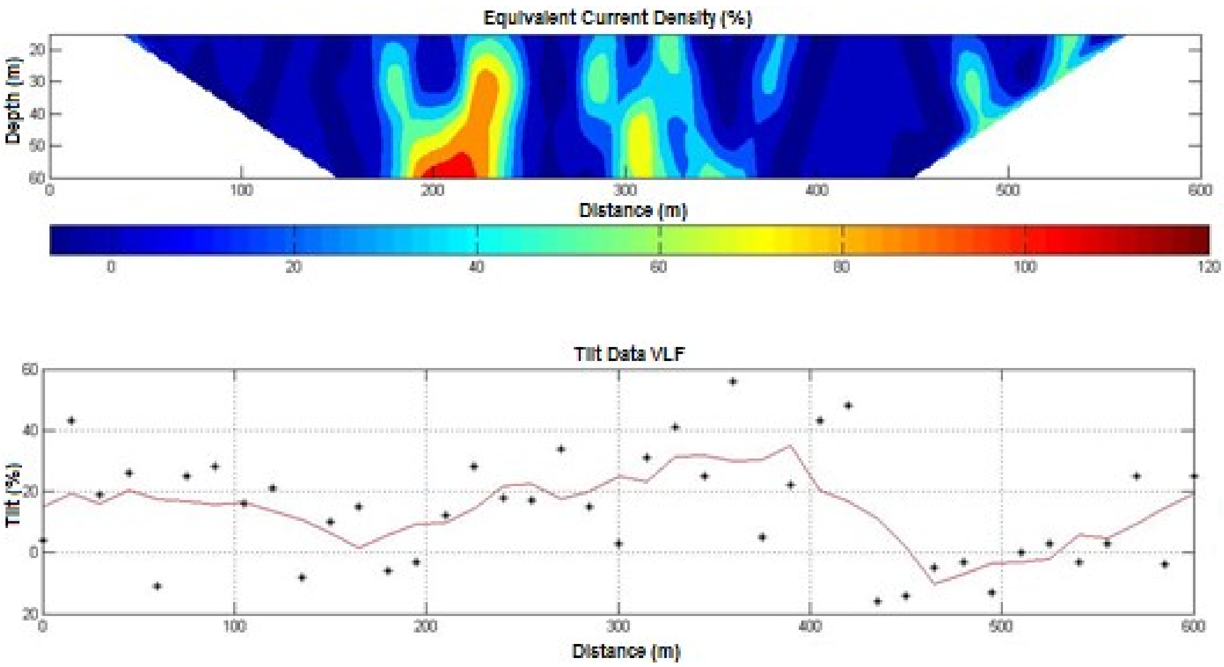

Figure 22. 2D VLF cross section in line 9

In **Figure 21** is a cross-section where the blue color gradient with a value range of (20 – 40)% is interpreted as hard limestone and the yellow to red color gradient with a value range of (60 – 120)% is interpreted as a cavity in the limestone which contains water as the target in the search.

underground river. In Figure 5.18 there is a cavity at a distance of 100 m, with a cavity size of around 5-10 m, at a distance of 200 m and 400 m there is a cavity with a cavity size of around 5-15 m.

Figure 22 shows a blue gradient with a value range of (20 – 60)%, interpreted as hard limestone and a yellow to red gradient with a value range of (80 – 140)%, interpreted as a cavity in limestone filled with water as a target in river tracing. underground. On this line, there are cavities at a distance of 200 m, with the size of the cavities being around 10-15 m, and at a distance of 300 m, there are small cavities around 2-5 m.

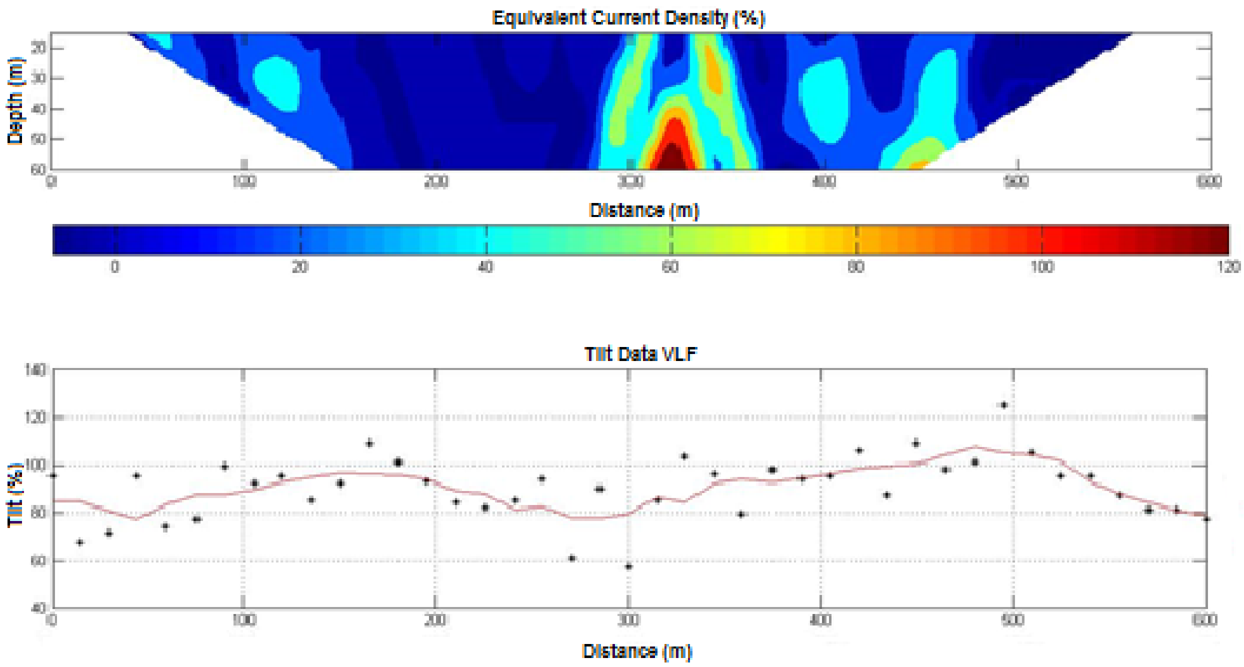

Figure 23. 2D VLF cross section on line 10

From **Figure 23** it is interpreted that there is a continuity of conductivity patterns. The blue color gradation with a value range of (20-40)%, is interpreted as hard limestone and. The yellow to red color gradation, which has a value range of (60-120)%, is interpreted as a cavity in the limestone that contains water as a target in tracing underground rivers. In Figure 5.20, there is a continuous cavity at a distance of 300 m, with a cavity size of around 10-15 m.

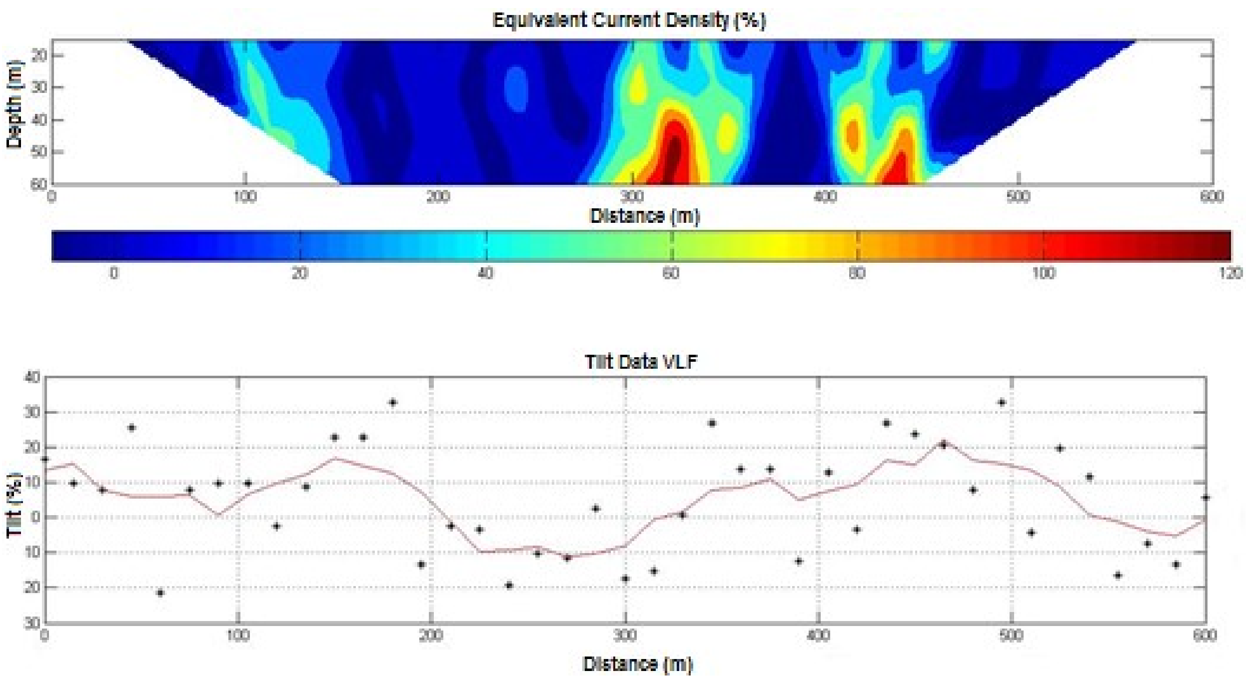

Figure 24. 2D VLF cross section on line 11

On **Figure 24** is a cross-section of ECD which has blue to red color gradations, each gradation has a different range of conductivity values. The blue color gradient with a value range of (20 – 60)% is interpreted as hard limestone and the yellow to red color gradient with a value range of (80 – 140)% is interpreted as a cavity in the limestone filled with water so it has a high conductivity value. In this research, the research target is high conductivity values which are thought to be underground river flows in the form of karst mountains. On this line there are cavities at a distance of 300 m and 450 m, with the cavity being around 10-15 m in size.

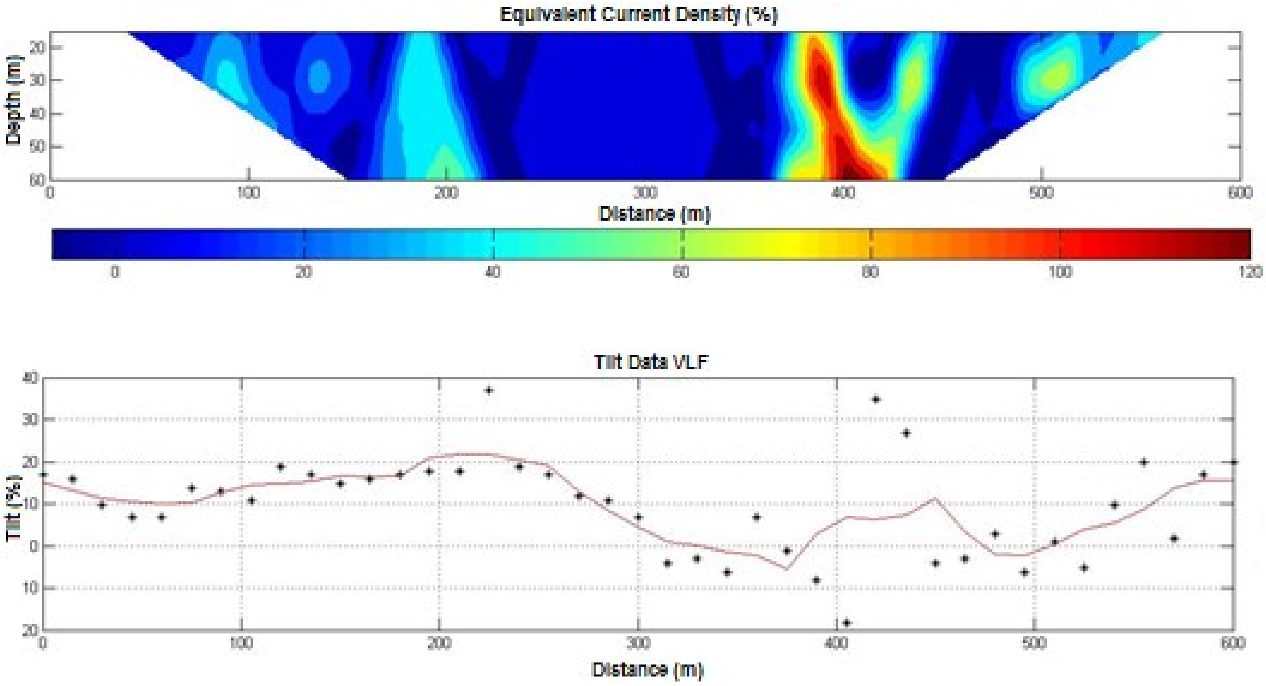

Figure 25. 2D VLF cross section on line 12

Figure 25 is an ECD cross section that describes the conductivity level of a rock. The blue color gradient with a value range of (10 – 40)% is interpreted as hard limestone and the yellow to red color gradient with a value range of (50 – 100)% is interpreted as a cavity in the limestone filled with water so it has a high conductivity value. On this line there is a cavity at a distance of 400 m with the size of the cavity being around 10-15 m. In this study, the research target is high conductivity values which are thought to be underground river flows in the form of karst land.

Figure 26 is an ECD cross section that describes the conductivity level of a rock. The blue color gradient with a value range of (100 – 200)% is interpreted as hard limestone and the yellow to red color gradient with a value range of (300 – 600)% is interpreted as a cavity in the limestone which contains water as a target in searching for underground rivers. On this line there is a continuous cavity at a distance of 150 m, with a cavity size of around 10-15 m.

Figure 27 is a 2D correlation of VLF cross sections compiled using MAPINFO software. High conductivity patterns are also present in the results of VLF data processing. High concentration in VLF reflects the ability of objects or rocks to conduct electricity so that it can be expressed in conductivity. In the study area, high conductivity closures are interpreted as areas or rocks that have or contain water. The results of this VLF processing show patterns of areas with interconnected water content. Equivalent current density (ECD) is a physical quantity that can be related to the level of conductivity of a rock.

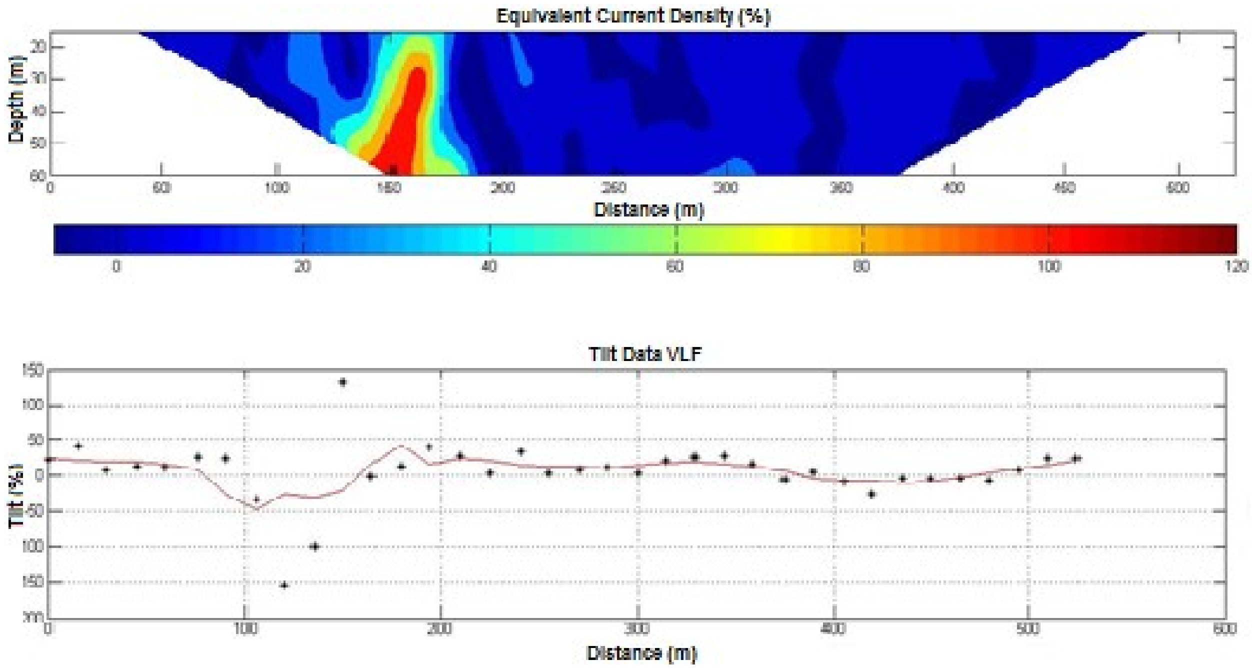

Figure 26. 2D VLF cross section on line 13

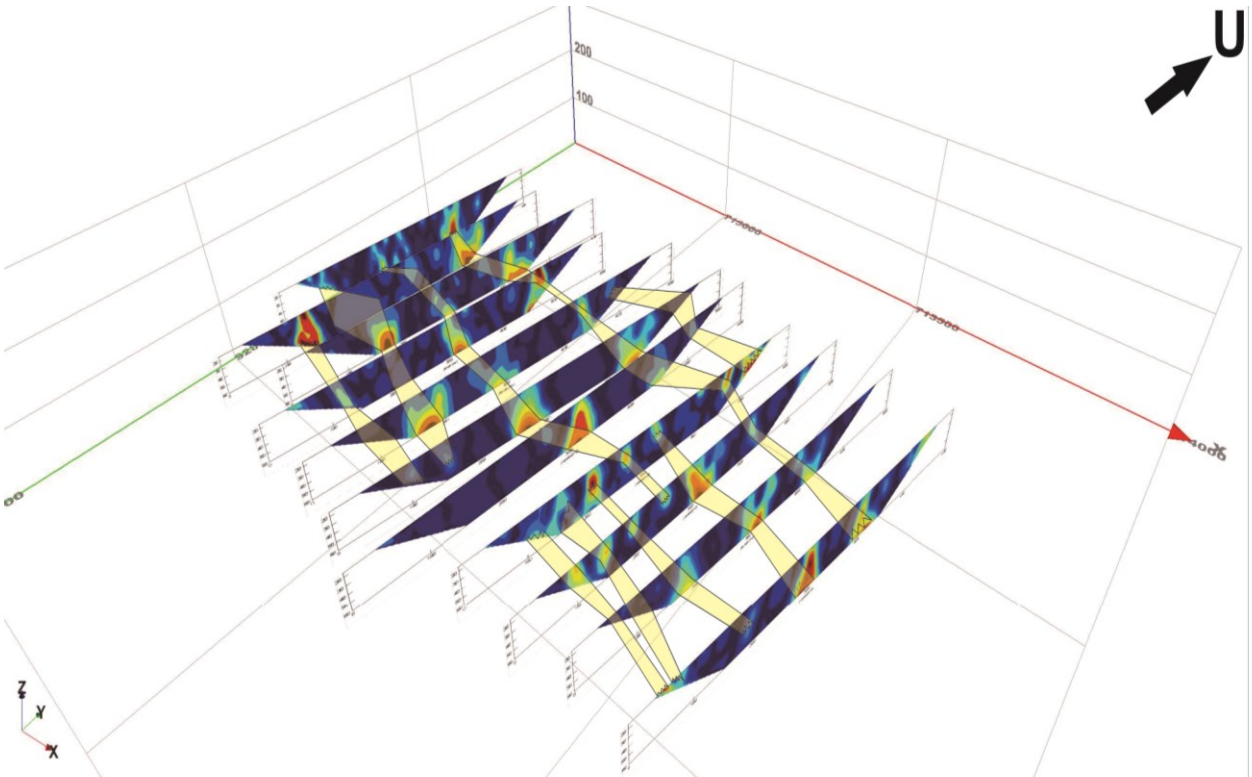

Figure 27. 2D correlation of VLF cross sections from line 1 to line 13

Equivalent current density is an electrical parameter or commonly referred to as electric flux (the number of electric lines that pass through an area). The equivalent current density is influenced by the electrical conductivity and permittivity values of an object. This high ECD value is caused by the presence of rocks that have large amounts of negative ions, namely shale or rocks that contain water. This is because these objects are able to conduct magnetic fields so they can be interpreted as having good conductivity.

The continuity of the underground river can be seen in **Figure 27** which reflects that from the first pass to the thirteenth pass there are many cavities with varying sizes ranging from 5 m to 15 m found below the surface so that in **Figure 27** shows the continuity of these cavities in a southeast direction. So the underground river in this study continues/flows towards the Southeast, by looking at the size of the cavity in each line.

CONCLUSION

The VLF method of interpretation and methods Geoelectricity Dipole-dipole configuration reflects the existence of a target that mutual support between the two methods. Correlation 2D Geoelectricity method also showed a cavity with a small resistivity which is interpreted as a the presence of water in each of the cavities on each line of data acquisition. The existence of the cavities of the potential occurrence of subsidence/collapse shallow. Continuity of the underground river leads to the Southeast, where the cavities formed by the underground river the size of the cavity is 5-15 m, with a distance almost equal to the depth of about 15-105 m.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest concerning the publication of this article. The authors also confirm that the data and the article are free of plagiarism.

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