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Determining the thickness of the weathering layer overlying the basalt in Cu Mga - Dak Lak area by 2D resistivity imaging

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ABSTRACT

The demand of water is increasing in many regions in Vietnam, especially in the Central Highland regions where in the dry season, the lack of water resources usually causes significant problems to people's living and agriculture. There have been many researches focusing on this area. However, the information of water - bearing structures is still limited, particularly for the local region because of a small number of projects dealing with this issue. To address this problem, in this paper, the authors implemented the 2D resistivity imaging in Cu Mga commune of Dak Lak province to determine the thickness of the weathering layer overlying the basalt, which gave important information to propose reasonable groundwater recovery plan for this local studied area. The results on 13 measuring profiles provided a detailed image of the geo - hydrological structures in the region compared to drilling and geological excavation data.

1. Introduction

Currently in many parts of Vietnam, especially in the Central Highlands region, where the area of basalt weathering cover is large, in the dry season, the demand for water resources is currently a matter of great concern. Along with the population increase, the expansion of cultivated land for industrial crops and short - term crops requires an abundant source of water to ensure sufficient water for domestic use and irrigation for the region export. However, due to excessive groundwater extraction and no specific planning, in addition to global climate change, the surface and groundwater resources are increasingly scarce. In many places such as Cu Mga, Krong Buk, Eaka, ... in the dry season, there is a serious shortage of water. Notably, in the area of Cu Su, Cu Mga district, Dak Lak province, immediately after the end of the rainy season about a month, surface water and groundwater resources are exhausted. Therefore, the study and evaluation of geological structure as well as the determination of water - bearing media, followed

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by proposing recovering measures on these bases, are extremely urgent for the life of people in this area in particular and the Central Highlands in general.

So far on the territory of the study area, there have been general studies on geology, tectonics in the South Central and South Central Highlands (Gatinsky et al., 1984; Viet Trieu Le, 2005; Yem Trong Nguyen, 1991; Tri Van Tran, 1985). Along with that, some other authors have studied and evaluated the vertical rate of fall of the water - level as well as proposed solutions to groundwater recharge for the Central Highlands region (Hieu Bui, Phi Quang Nguyen, 2011; Canh Van Doan, 2003; Canh Van Doan, 2007; Canh Van Doan, 2010; Viet Trieu Le et al., 2016). However, the above studies are still general or have focused mainly on the results of aquifer exploration drilling under individual projects. Specific studies on local regions are few, especially where the basalt cover exits. The accuracy of the identification of different vertical geological strata is low due to the interpolation from a small number of bore - holes. Meanwhile, to propose a reasonable groundwater recovery plan, to serve the needs of living and production, there must be intensive research at each specific area, incorporating the results of geological and geophysical studies.

In the framework of this paper, the authors present the latest geophysical results of Chu Sue commune area. Integrating with the geological structural characteristics of the area, the authors have determined the thickness of the weathered crust on basalt, the structure which is capable of storing underground water, and proposed the most reasonable groundwater recharge plan in the study area. After the introduction, the location and geological and tectonic features of the study area will be generalized. Next, the authors will introduce the research methods applied to determine the weathering crust thickness on basalt in the area. The last part is the results obtained on geophysical profiles and the conclusion of the ability to recharge groundwater into this structure.

2. General information on the study area

The study area is located in Cu Sue commune, Cu M'Ga district, Dak Lak province, limited to coordinates from 108^0 00 ' 00" to 108^0 08 '00" east longitude and from 12^0 44' 13" to 12^0 48'09" north latitude (Figure 1). This is a densely populated area with industrial crops and food

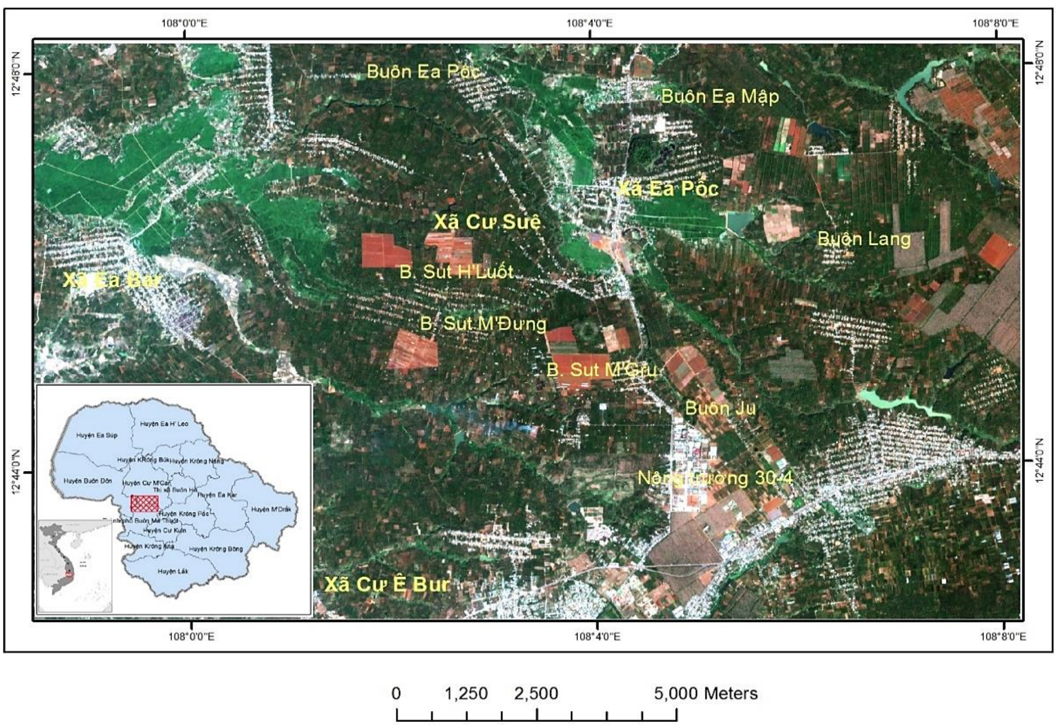


Figure 1. The study area.

crops. This region has a long dry season, which makes it difficult to supply water for irrigation and for people.

The topography of the study area is a sloping surface divided by the NW - SE river system, creating the slopes with the longitudinal peaks of the same direction and the altitude decreases in two directions East to West (from the center of Cu Sue commune to Thon 4) and north - south.

In terms of geology, according to documents (Bui Van Thơm, 2018; Tu Tuan Ngo, 1999; Tien Dinh Nguyen, 1999; Tri Van Tran, 1985), the study area is an ancient syncline which consists of claystone, siltstone, and limestone of La Nga formation, overlaid by basalt and their weathered crust

3. Materials and methods

3.1. The relationship between electrical resistivity and geological structures

Geological data and exploration drilling results show that there are three basic geological formations in the study area: La Nga (J_2 ln) formation, basalt eruption of Tuc Trung formation (βN_2 - Q_1 tt) and the Quaternary sediment. (Map1 Geological and mineral map at the scale of 1: 200.000 including: Ban Don, Ben Khe, B'Lao, Buon Ma Thuat and Buprang. Archive General Department of Geology and Minerals of Vietnam (2010).

La Nga formation has components including medium to thin - layered sandstone, siltstone, and clay. In some boreholes, the top of this formation lies at a depth of about 70 - 80m, with rocks have medium level of fractures. The rocks' minerals of La Nga formation have low conductivity. Therefore, their resistivity parameters are of high value in dry media. However, the aquifers in the ancient rocks belong to La Nga formation, mainly concentrated in tectonic fracture zones, have low resistivity values.

The Tuc Trung formation (βN_2 - Q_1 tt) is an olivine basalt eruption with complex form, porous form, and foam. These layers interweave, sometimes in lens form. Cu Sue volcanic throat, located about 1 km east of the study area, may be the source of basalt lava flows from east to west. This may be the reason for the basalt rock in the study area to have high electrical conductivity, due to the mineral components containing the metal interconnected in the process of rock formation.

In the scope of the study, the weathering layer of basalt has the composition from top to bottom as follows: sand, macadam compacted in thickness from a few centimeters to a few dozen cm; sand, mixed sand, red - brown to yellow - brown mixed clay in thickness, varying from 30m in the east to a few meters to the west; semi - weathered basalt from foamy, strong fractured basalt, soaked in water, soft and flexible rock but still retains the original structure of the original basalt. This weathering crust has a much higher resistivity value than the underlying basalt layer, except for those related to the tectonic fractured zone containing water. The high resistivity value of most of the weathered crust may be due to the water - containing portions of the foamy basalt unconnected. Sand, clay, dry shavings also have high resistivity.

Quaternary sediments (Q_2), distributed in the west of the study area, they are aluvi or aluvi - proluvi mixture originated from rivers and streams, comprising sand, mixed sand, macadam and gravel with the thickness varies from 1 - 3m. The distribution area of Quaternary sediment is concentrated in low - lying strips extending along the big stream, further downstream of the valley. This sediment often contains water so it has low resistivity, and is directly related to tectonic faults in the Cenozoic phase of the study area. However, because the thickness is too thin and distributed in a narrow area, the Quaternary sediments are rarely shown on the electrical resistivity images.

Two - dimension (2D) electrical resistivity method is conducted in the study area in the dry season. Therefore, the conductive properties of rock layers can be generalized as follows: high resistivity of weathered crust and bed rocks, and low resistivity of basalt layer and tectonic fracture zones. This is the basis for determining the thickness of weathering crust on basalt and the thickness of basalt layer in the study area by 2D electrical soundings.

3.2. The electrical sounding method

The electrical sounding is the method of studying the change of apparent resistivity in the depth (vertical) by maintaining the position of the measuring point and gradually increasing the electrode spacing to increase the investigation depth to identifying geological objects or stratigraphic interfaces in depth. This is a method to study the electrical properties of rock and soil through a direct current electric field (Loke, M.H., 2002).

As the definition above the apparent resistivity measured in this method is a function depending on the electrode spacing, i.e. $\rho_k = f(r)$.

$$\rho_k = K.\Delta U/I \qquad (1)$$

Where r is the parameter related to the electrode spacing; K (r) is a device coefficient, a function depending on r; ΔU is the voltage difference between two potential electrodes; I is the current flowing into the environment through two current electrodes.

The method, depending on how the measurement is carried out and the inverted model obtained, is divided into 1D, 2D, and 3D methods.

In this study, the authors used the 2D resistivity imaging method to separate weathering crust on basalt. This method is commonly used in relatively flat terrain conditions, and geological structures are divided according to electrical resistivity without substantial changes in all three dimensions. With the above - mentioned geological setting, according to the depth of research from bottom to top, there are sedimentary rocks, basalt eruptions, weathered crust on basalt and Quaternary sediments. These horizontal layers of rocks, in some areas, are divided and shifted by faults. Therefore, the 2D resistivity imaging method is suitable for research in this area.

Figure 2 shows the array configurations of the Wenner (W) and Wenner - Schlumberger (W - S) arrays, with C1, C2 being the current electrodes transmitting the direct current into the earth; P1, P2 are potential electrodes measuring the potential differences; n is the number of smallest electrode spacing (a). In the 2D resistivity imaging method, the depth increases when increasing the value of n, i.e. the further distance between the electrodes, the deeper the current flows into the earth, which increases the depth of research. In the 2D electrical imaging method, on a certain profile, there are arranged M points separating by "a" spacing (Figure 3), which increases the horizontal resolution of this method compared to 1D vertical electrical sounding. Wenner and Wenner - Schlumberger arrays are also called symmetric arrays. In addition, this 2D electrical sounding method also has other types of the array such as pole - pole, pole - dipole, dipole - dipole, equatorial - dipoles. In practical surveys, the symmetric array is widely used due to its simplicity and ease of construction compared to the remaining methods (Nga Trong Nguyen, 1996). Compared to the Wenner array, the resolution of the Wenner - Schlumberger array is higher, allowing for more accurate identification of objects with relatively small horizontal dimensions (Loke, M.H., 2002).

The apparent resistivity value at the data points in Figure 3, corresponding to each "n" value, is calculated as follows:

$$\rho_k = \pi \times n\ (n+1) \times a \times \Delta U/I \qquad (2)$$

After the measurement process, the data on each profile was saved and inversed by specialized software RES2DIV (6). The result is a geo - electrical pseudo - section representing the distribution of resistivity values on the profile.

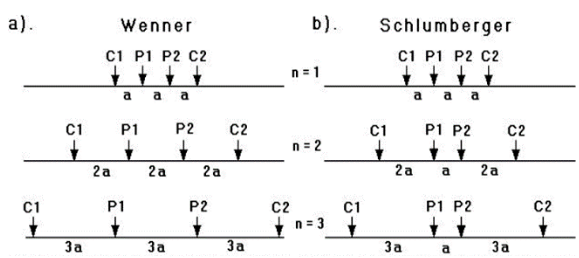
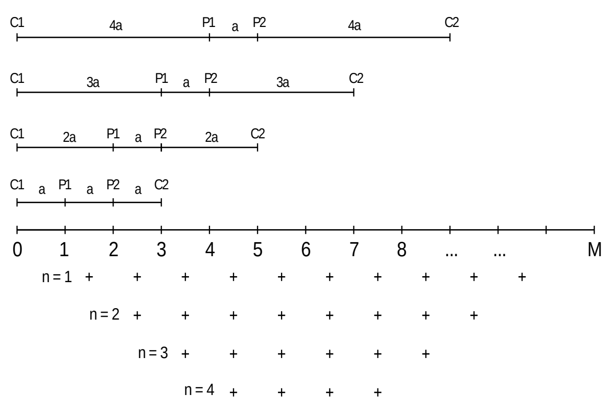


Figure 2. (a) Wenner and (b) Wenner - Schlumberger array configurations (5).



Hình 3. Arrangement of data points in the pseudosection for the W - S array with n varying from 1 to 4.

After the measurement process, the data on each profile was saved and inversed by specialized software RES2DIV (6). The result is a geo - electrical pseudo - section representing the distribution of resistivity values on the profile.

There are many factors affecting the resistivity value of rock and soil such as conductive mineral content, architecture, the structure of geological objects, temperature, pressure,... (Nga Trong Nguyen, 1996). As mentioned above, because the investigation depth is not large (from a few tens to about 100m), the effect of temperature and pressure on the resistivity value on the obtained geo - electrical pseudo sections is not large. The main factors affecting the resistivity of the studied objects are the content of conductive minerals associated with basalt eruption, the level of water contained in the pore of rocks and the faults.

4. Results

4.1. 2D resistivity survey designation

The task for geophysical measurement is to determine the geological structure, namely the boundary surfaces, the thickness of the layers, the tectonics fracturing zones,... Based on the terrain, we have designed the 2D resistivity imaging profiles in two main directions North - South and East - West, ensuring cutting through the main terrain and geological structure. There have been 13 profiles conducted in Cu Sue commune (Figure 4). In which, the first 5 ones (T1 - T5) are arranged through the main geological structures of the study area. From the survey results of the profiles mentioned above, we selected the southeastern region of the study area as the location where detailed research is needed. The profiles from T6 to T13 are measurement lines to detail the structure for the area of interest.

Figure 4. The 2D resistivity imaging profiles configuration.

4.2. Results on 2D resistivity imaging profiles

In the content of this paper, we analyze the results on the 2 profiles T1 and T2, because they go through the typical structures of the study area.

Figure 5 is the inversed resistivity cross section (upper) and the geo - electrical cross section (bottom) of a 2D resistivity imaging on the T1 line. The T1 line has a total length of nearly 2 km, with 40 measuring points, the distance between measuring points is 50 m. The depth of investigation on the whole route is more than 100m. The inversion result of this line shows that the resistivity value on the cross section varies from a few tens to more than 1000 Ohm.m. The resistivity values on the whole line are divided into 3 layers quite clearly. The top layer from the surface to a depth of about 20 m (depending on the position on the profile) has medium to large resistivity values and has a local variation that is typical for the weathered crust. The thickness of this layer increases gradually at the end of the profile. The second layer is distributed from a depth of about 20 m to 70 m with lower resistivity values than the upper layer. This is a layer of basalt containing conductive minerals. The third layer, distributed from a depth of about 70m or less, has higher resistivity values, which may be the presence of the bed - rock. At some locations (150 m; 850 m; 1200 m; 1650 m; 1900 m) on the cross section there are low resistivity anomalies. These anomalies may be related to tectonic faults that break the rocks that it penetrates and contain water. Based on the results of the resistivity imaging and the prior geological information, we have constructed a geo electrical section that divides the rock layers and determines the fault location as shown in Figure 5.

On the resistivity cross section in Figure 6, we see that the resistivities value across the profile varies from a few tens to over 1000 (Ohm.m). On the whole cross section, the resistivity values are divided into three layers in accordance with the general characteristics of the study area. The top layer is distributed from the surface to a depth of approximately 20 m with varying resistivity values from medium to high and with local differentiation showing the weathering crust.

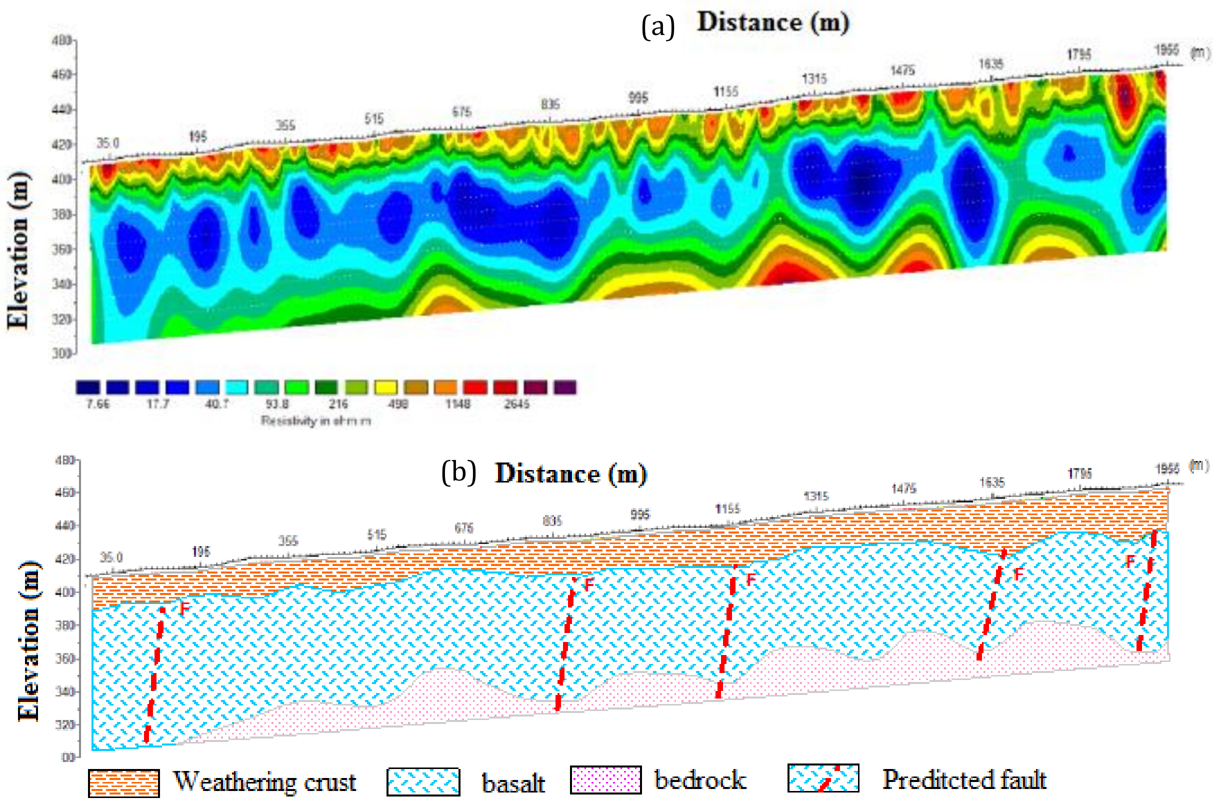


Figure 5. The 2D resistivity imaging result on profile T1: inversed resistivity cross - section (a) and geo - electrical cross - section (b).

This layer has a stable thickness from the beginning of the route to 1150 m on the profile, and is very thin in the stream area from 1200 m to 1400 m. At the position of 1350 m, basalt appears, so there is no presence of the weathering crust on the cross - section. From the position of 1475 m to the end of the profile, the thickness of this layer gradually increases. The second layer has lower resistivity values because of the basalt layer containing minerals that have high electrical conductivities. This layer has a thickness of about 30 m to 40 m and there are variations on the whole line. In the area of the beginning of the profile to the position of 835 m, the basalt layer shows a gradual thinning and distributes within natural elevations from 420 m to 360 m. In the area of the stream bed, the location of 1350 m of basalt layer is clearly visible on the surface and can be easily seen in the field. At the end of the profile, this layer tends to thicken and distribute deeper. The third layer has higher resistivity values than the middle layer distributed in depths with the elevation of 360 m or deeper. This layer is only caught, on the inversed cross - section, from the positions between 200 m and 1800 m. This is the bed rock layer under the basalt layer. The resistive anomalies that occur at the positions of 835 m to 1200 m on the T2 profile are higher resistivity than the surrounding area, but lower than the weathered crust and the bed rock layer. These anomalous blocks may be related to fractured zones with the direction is nearly east - west. Points 195 m and 1955 m on the profile are also the locations with low resistivity anomalies related to the faults, tectonic fractured zones with the east - west direction that the profile crosses. Below the inversed resistivity result in Figure 6 is the geo - electrical section explained from the 2D resistivity imaging results on the T2 profile.

The geological implication in the study area

In the study area, some authors have identified different geological strata (Viet Trieu Le et.al (2015), Viet Trieu Le et al (2016), Tu Tuan Ngo et al (1999)). Recently Bui Van Thom et.al. (Thom Van Bui (2018)) divided into 3 geological layers corresponding to 3 aquifers: (i) Aquifers in the weathered crust of basalt; (ii) Aquifer in basalt (porous basalt) (iii) Aquifer in ancient rock (claystone, siltstone).

Based on the results of geo - electrical cross sections analysis on all profiles in the survey area, the authors have developed a topographic diagram (Figure 7), two iso - depth diagrams of the top of basalt layer (Figure 8) and of sedimentary rocks of La Nga formation (Figure 9). In Figure 7, we see that the terrain of the study

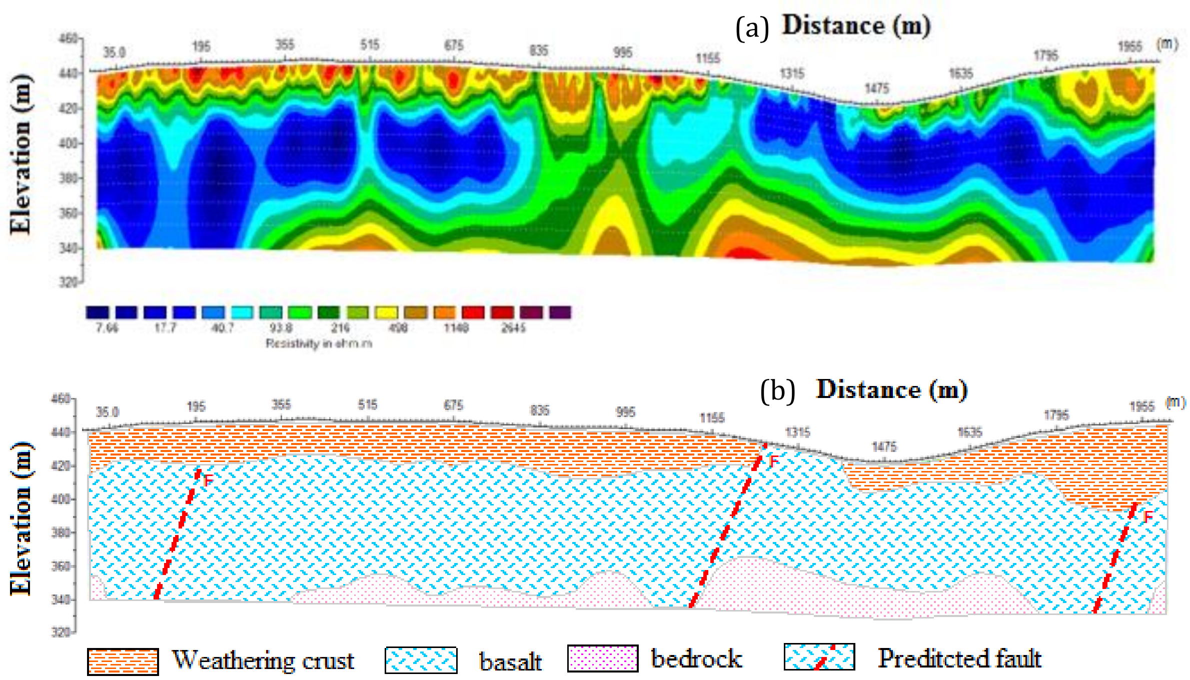


Figure 6. The 2D resistivity imaging result on profile T2: inversed resistivity cross section (a) and geo - electrical cross - section (b).

area shows a decrease in elevation from the northeast to the southwest. The terrain difference of the study area is up to 60m (from elevation of 400m to 460m). The top surface of basalt layer also tends to change according to the topographic surface (Figure 8). In the east of the area, the highest point of the iso - depth of the top of basalt layer corresponds to a height of 433 m. Meanwhile, the lowest point in the southwest area corresponds to a height of 393 m. From the results in Figures 7 and 8, we can see the largest thickness of weathering crust in the eastern region and tends to thin down to the west, in the southwest this layer has the smallest thickness.

The top surface of the bedrock (including the siltstone, sandstone of La Nga formation (J2 ln) has less variation than the basalt surface (Figure 9). This surface has the highest in the northeast, corresponding to the natural elevation of 347 m and tends to decrease to the southwest at 332 m altitude. According to Figure 8 and Figure 9, the distribution on the study area of the thickness of the weathered layer is the same as that of the basalt layer beneath it.

The above results are consistent with drilling information and geological excavation of the study area.

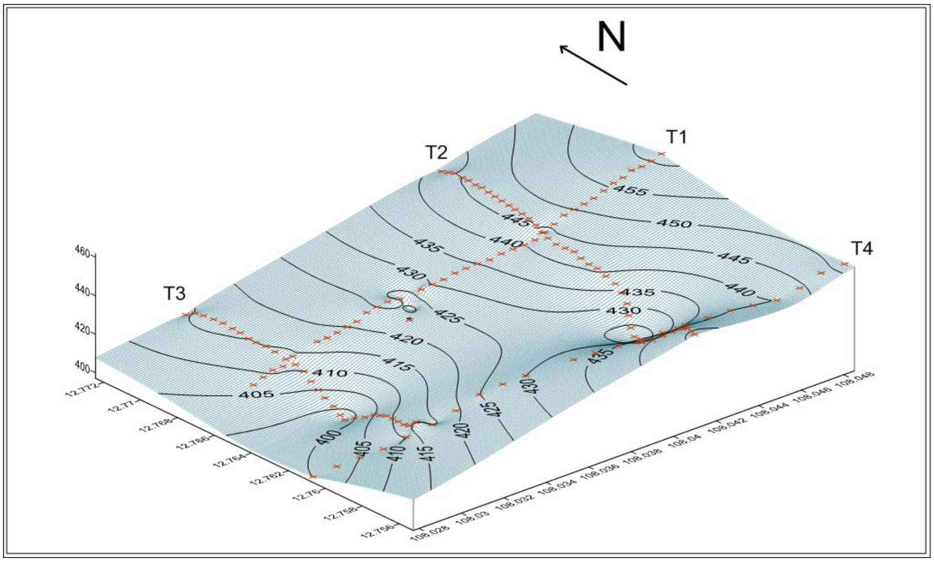


Figure 7. Topographic diagram of the research area.

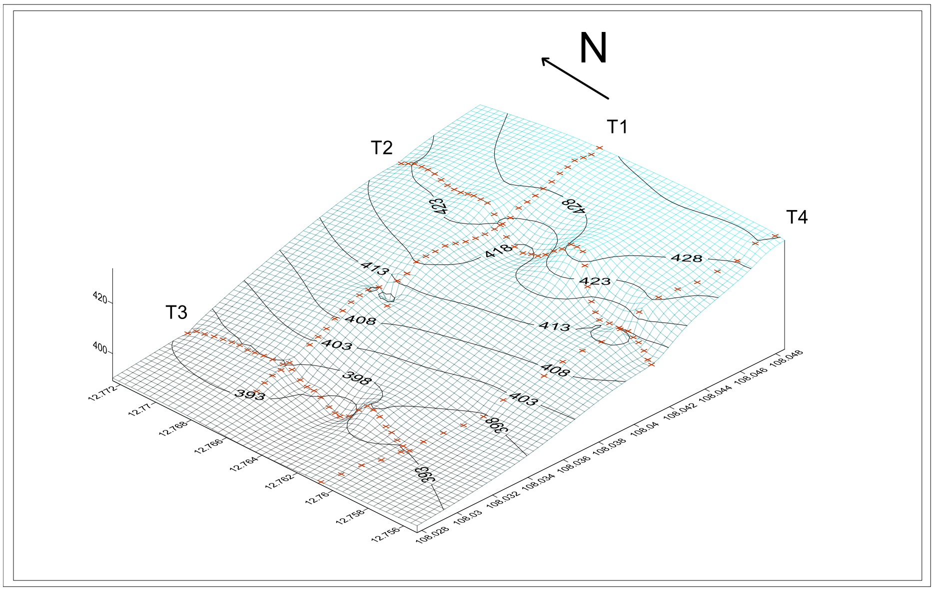


Figure 8. Iso - depth diagram of the top of basalt layer.

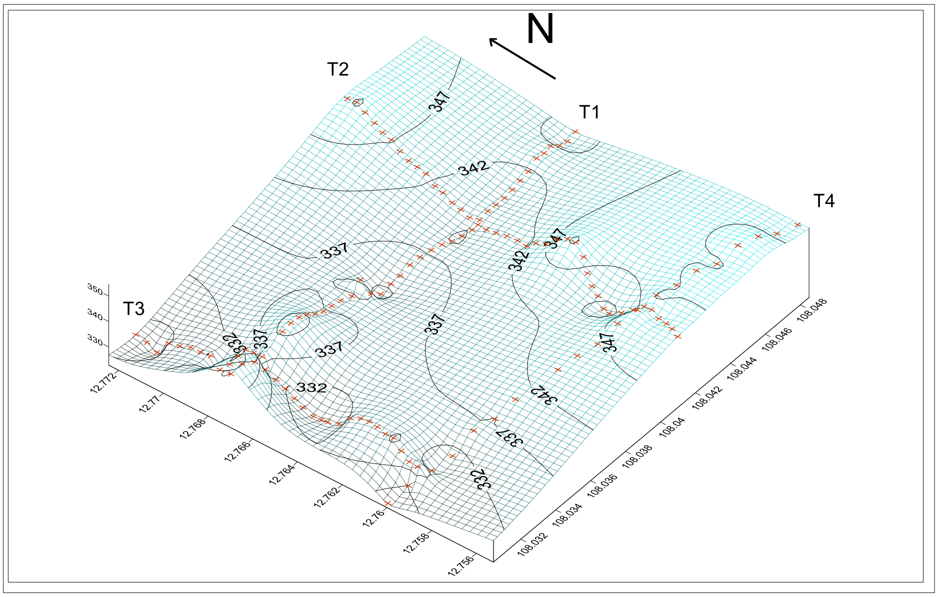


Figure 9. Iso - depth diagram of the top of the bedrock of La Nga formation.

5. Conclusion

The method of 2D resistivity imaging has been effectively applied in the study of dividing the interfaces among weathering crust, basalt, and bedrocks, determining the thickness of the rock layers, delineating the locations of the fractured tectonic zones. The results of the geological interpretation from the resistivity imaging help to more accurately assess the distribution of aquifers in the study area, as a basis for proposing management measures and exploiting underground water effectively. From the 2D electrical resistivity results, the iso - depth diagrams of the top of important geological strata (basalt, bedrock...) have been built with high detail and contributed an important part in accurately determining the different aquifers, water - bearing zones, groundwater lowering structures ... The geophysical results show that it is more accurate and effective than other methods, especially in local areas with basalt coatings.

The characteristic of low resistivity of basalt layers containing conductive minerals has been shown in this study. This conductive property is easy to confuse basalt with low resistivity water zones during geological interpretation. Therefore, the authors recommend that the interpretation of the inversed resistivity cross - section coupled with the other documents should be carefully implemented in this region of interest.

6. Acknowledgment

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