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Research article

Assessing groundwater potential for watering coffee plants in household using geoelectric parameters: A case study in Cu Jut, Dak Nong

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ABSTRACT

The electrical resistivity investigation conducted on a property in Cu Jut, Dak Nong, had the overarching objective of assessing the groundwater potential for coffee cultivation. This local-scale project employed a comprehensive approach, involving three Vertical Electrical Sounding (VES) points, four 2-D imaging profiles spanning four survey lines, and a sophisticated 3D visualization for in-depth area analysis. The quantitative interpretation of VES curves was a pivotal aspect of the study, executed with precision through partial curve matching and computer-assisted 1-D forward modeling using IPI2 win software. This meticulous approach facilitated the identification of four distinct geological layers in the study area. The topsoil layer, although shallow, was found to lack significant hydrogeological properties. Below this, a partially weathered basalt layer emerged as a small aquifer unit, exhibiting thicknesses typically ranging between 10 to 15 meters. However, its hydrogeological significance was moderate. The interleaved arrangement of porous and tight basalt layers, constituting the primary aquifer, emerged as a key finding. Characterized by resistivity values generally below 300 ohm-meters, this aquifer displayed low permeability and porosity, suggesting a limited capacity for groundwater storage. The basement rock marked the concluding layer in the geological profile. Integrating data from both 2-D imaging profiles and 3-D visualization, the study delved into assessing potential water depth and estimating water volume. Utilizing contour maps, the research also identified optimal locations for well drilling. In essence, the study's findings point towards the interleaved porous and tight basalt layer as the primary aquifer with substantial potential for groundwater supply. Contrarily, other geological layers were deemed to have limited hydrogeological significance. This holistic assessment, supported by advanced resistivity methods, provides valuable insights for sustainable water resource management, particularly in the context of coffee cultivation in Cu Jut, Dak Nong.

Key words: vertical electrical sounding (VES), 2D imaging, 3D imaging, IPI2 win software, groundwater, geoelectric

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INTRODUCTION

Vertical Electrical Soundings (VES) are widely employed in groundwater investigations due to their cost-effectiveness, non-invasive nature, and ability to provide crucial insights into subsurface geological conditions. VES method has been widely employed to investigate groundwater characteristics. For instances, in the northern part of Sukoharjo district, this approach was utilized to determine groundwater depths for agricultural irrigation [1]. The study shown clearly comprising layers of topsoil, sand, gravel, and clay rocks. Another study [2] conducted in northern Morocco involved 47 VES survey to explore Quaternary basaltic aquifer formations. The results provided crucial insights into the geometry, vertical and lateral extent of the aquifer, and the identification of fault and fracture zones, which have practical implications for optimizing borehole placement for groundwater exploitation in the region. Additionally, in Igbo-Imabana, Cross River State, VES using the Schlumberger array were carried out to assess aquifer characteristics [3]. This study identified multiple geo-electric layers and heterolytic lithofacies, shedding light on the limited transmissivity in the area, which helps explain the frequent borehole failures experienced. These studies collectively highlight the valuable role of VES in groundwater investigation and its relevance to addressing critical groundwater issues in various geographic contexts.

Cu Jut, Dak Nong Province situated in the Southern Tay Nguyen plateau, Vietnam features low hills and valleys at an elevation ranging from approximately 300 to 500 meters above sea level. The groundwa-

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ter in the basaltic terrain exhibits a complex hydrodynamic system due to its formation during various geological periods, resulting in the intercalation of water-bearing and dry basalt formations. While the drilled wells provide sufficient water during the wet season, water scarcity is a concern during the dry season. The geological survey conducted in the area identified four distinct basalt zones[4]: a top zone with entirely weathered red-colored basalt mixed with gravel laterite and clay, a partially weathered zone with gray and reddish-brown basalt[5] that was crumbled and fractured, a zone featuring both tight and porous basalt with potential water content, and a bottom zone with tight basalt, limited fractures, and poor water storage capacity. Notably, tight basalt displayed high resistivity, while fractured and porous basalts had low resistivity, likely indicating water presence. Additionally, resistance in the weathered basalt clay and silty clay zone was high when dry but dropped significantly when wet. Due to the area's geological heterogeneity, the Wenner array method was employed for geophysical exploration to address the research objectives.

Recent industrial growth, particularly in the coffee industry in Cu Jut Dak Nong, has strained groundwater resources. To address this, geophysical surveys, notably electrical resistivity methods, have been employed for cost-effective subsurface assessment and aquifer identification in the complex crystalline basement terrain. The use of Vertical Electrical Sounding (VES), 2-D, and 3-D imaging surveys aims to optimize the survey system economically while meeting local water needs and drilling challenges[6]. The utilization of geoelectric surveys and software tools like Res2dinv[7], Surfer 10[8], and Matlab[9] allows us to assess potential water sources, estimate water volume, pinpoint drilling locations, and determine the depth of drilling targets within the basement rock. This approach aims to minimize risks associated with drilling for residents and achieve cost savings.

METHODOLOGY

The Vertical Electrical Sounding (VES) method is a geophysical technique used to investigate subsurface electrical resistivity variations. It involves measuring the electrical resistivity of the ground at different depths by inserting a pair of electrodes into the earth's surface and applying an electrical current through them. The VES method records the voltage drop between these electrodes and uses this data to calculate the resistivity of the subsurface materials.

By varying the separation between the electrodes and the depth of penetration, VES surveys can provide information about the underground geology and the presence of subsurface features like aquifers, bedrock, and mineral deposits. This method is commonly used in geological and environmental studies, as well as in groundwater exploration and mineral exploration to map and characterize subsurface structures and resources[10].

VES array configuration

The Wenner array method is employed to study changes in apparent resistivity with depth. Figure 1 illustrates the electrode arrangement and measurement sequence for a 2-D electrical imaging survey. Typically, this survey is conducted using a system where electrodes are positioned in a line, maintaining a consistent spacing between adjacent electrodes but with non-uniform electrode intervals. To accommodate the depth distribution of the water zone, which extends to approximately 100 meters, we selected a maximum survey line of 400 meters, with electrode spacing ranging from 10 to 100 meters[11].

Acquisition data

In the study area, three Vertical Electrical Soundings (VES) were conducted using the Wenner configuration, where the electrode spacing ranged from 10 to 100 meters. Data acquisition was carried out using a resistivity meter, and the positions of the sounding stations were geographically referenced using a Global Positioning System (GPS) unit[13]. The VES data were graphically represented as field curves, plotting apparent resistivity (ρ_a) against AB/3.

To quantitatively interpret the data, partial curve matching was employed to derive initial estimates of resistivity and thickness for various geoelectric layers at each VES station[14]. These geoelectric parameters served as the starting model inputs for computer-assisted 1-D forward modeling using IPI2 win software. Position and groundwater potential maps were generated based on the interpreted geoelectric parameters using 'Surfer' software version 10 or Matlap. Additionally, Res2div and Voxler 4 were utilized to visualize depth, volumes, and flow directions[11].

RESULTS AND DISCUSSION

VES curve types

The VES stations provide interpreted results derived from the sounding curves, allowing us to observe and comprehend specific characteristics of the subsurface layers. These findings are thoroughly discussed within the geoelectric sections. Figure 2 serves as a base map of the study area, pinpointing its location. The resistivity-sounding curves obtained from

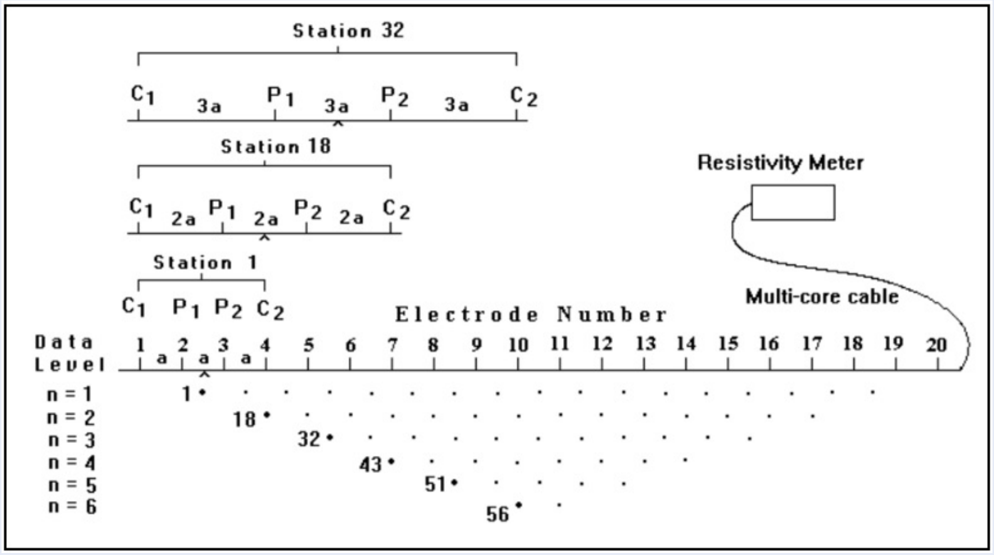

Figure 1: Sequence of measurements to build up [12]

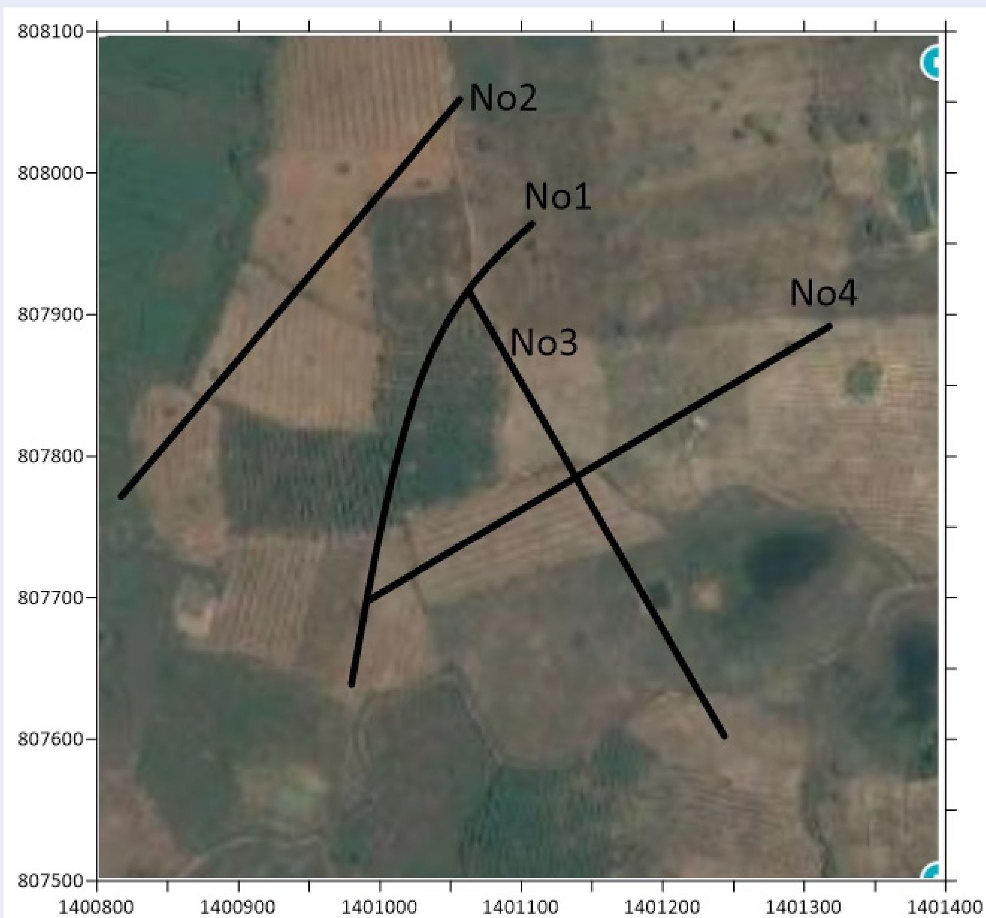

Figure 2: The location of VES stations

the surveyed area have been categorized into four layers, as shown in Table 1 and Figure 3. KH curve is determined as typical interpreted curve for all VES stations. Theoretically, KH curve[15] has the resistivity value of 4 respective layers follow $r_1<r_2>r_3<r_4$.

The results in Figure 3 demonstrate that at VES line number 2, the soil and rock layers are divided into four main layers. These include the top layer with low resistivity, characteristic of weathered rock components. Next is the second layer, characterized by high resistivity, followed by the third layer with low resistivity, indicating weathered rock. The bottommost layer exhibits high resistivity exceeding 10,000 Ω.m, characteristic of unweathered rock. This complexity in geological characteristics within the research area highlights the need to conduct Electrical Resistivity Tomography (ERT) survey to gain a comprehensive and detailed understanding of the studied subject, allowing for a more precise evaluation of weathering characteristics and water-bearing potential in the area.

2D Electrical imaging survey

Currently, two-dimensional (2-D) electrical imaging surveys are widely utilized to map regions with complex geological structures, offering enhanced accuracy compared to traditional 1-D resistivity sounding surveys. It has become a standard geophysical technique, allowing us to visualize the distribution trend of resistivity patterns in the study area. The 2-D resistivity structure reveals significant variations in rock or lithology resistivity at various depths along the profiles (Figure 4 for survey line 2).

Across all profiles, there is a concentration of potential water areas ranging from 15 to 35 meters deep, indicating a propensity for high groundwater capacity within the fractured and porous basement rock which has high weathering. The resistivity values for fractured and porous basement rock at various VES stations in the study area ranged from 20 to 6000 Ω.m, highlighting significant heterogeneity in material composition. To assess groundwater potential, a classification scheme based on fractured and porous basement resistivity was developed and is presented in Table 2. This classification demonstrates that resistivity in the range of 20 - 100 Ω.m corresponds to high weathering and groundwater potential. On the contrary, resistivity values exceeding 300 Ω.m are indicative of the absence of an aquifer.

3-D Electrical imaging survey

To assess the detailed characteristics of the water-bearing structure in our area, we created a 3D resistivity map. We leverage three-dimensional grids that encompass survey depth, GPS coordinates (X,Y), and resistivity data to focus on volumetric representations. This approach offers superior visualization compared to 2-D imaging profiles, providing insights into the depth of potential aquifers, optimal drilling locations, and resistivity isovalue levels (Figure 5). Notably, the isovalue levels help elucidate the flow directions within the aquifer, enhancing our understanding of its movement.

Using Surfer 10, we've created iso-resistivity maps for survey layers, aiding in the identification of specific layer areas, depths, and GPS coordinates. This feature allows for the convenient placement of reference points on these layers, and showing 3D (X, Y, Z) coordinates. Figure 6 illustrates the iso-resistivity map for two significant layers at depths of -18.5 and -25 meters, both related to potential aquifers. You can customize the color scale bar to assign colors to resistivity values as desired.

The electrical resistivity data varies with spatial coordinates and depth in the subsurface. The interpolation and extrapolation processes assist in constructing the resistivity map in the initial research area Figure 7. Subsequently, by refining and eliminating inappropriate noisy values, we obtain the resistivity map as shown in Figure 8, illustrating a clear distribution of resistivity values at a depth of 25 meters.

Based on the analysis of the water-bearing potential according to Table 2, we proceed to display the resistivity values less than 100 Ω.m and 50 Ω.m Figure 9 and Figure 10, characteristic of high-weathered layers with good water potential. Consequently, we identify the location with the lowest resistivity value and a significant area distribution based on Figure 9. We propose a feasible drilling location at coordinates X 807716, and Y 1401142, and a depth of approximately 33 meters.

CONCLUSION

In summary, geoelectric parameters play a crucial role in enhancing the understanding of the lithology and characteristics of an area through quantitative geophysical surveys. Especially, these geoelectric parameters are vital for evaluating potential aquifer locations, their depths, and optimal drilling positions. By using those, owners can prevent costly and time-consuming drilling errors, ensuring efficient well production. Based on the findings, it is recommended to drill into a porous and fractured layer with a medium to high groundwater potential, typically found at depths ranging from 20 to 35 meters. This layer falls within the optimum weathering resistivity range of 20

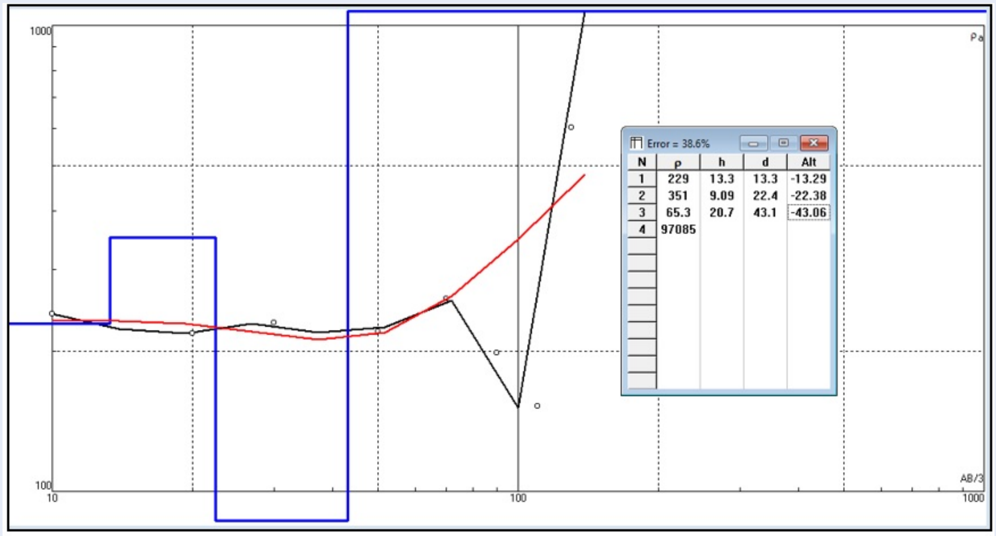

Figure 3: Interpreted field curves of the VES No.2 showing KH-curve

Table 1: Summary of the interpreted result of the sounding curves.

VES No.	Curve type	Layer	Resistivity (W.m)	Thickness (m)
1	KH	1	93.1	11.6
		2	9533	10.3
		3	135	20.4
		4	>10000	
2	KH	1	229	13.3
		2	351	9.09
		3	65.3	20.7
		4	>10000	
3	KH	1	138	3.94
		2	864	10
		3	282	11.7
		4	>10000	

Table 2: Aquifer potential as a function of resistivity of the study area

Fractured and porous basement resistivity	Aquifer characteristics
20 – 100 Ω.m	High weathering and groundwater potential
101 – 150 Ω.m	Medium aquifer conditions and potential
151 – 300 Ω.m	Less weathering and poor potential
>300 Ω.m	Negligible

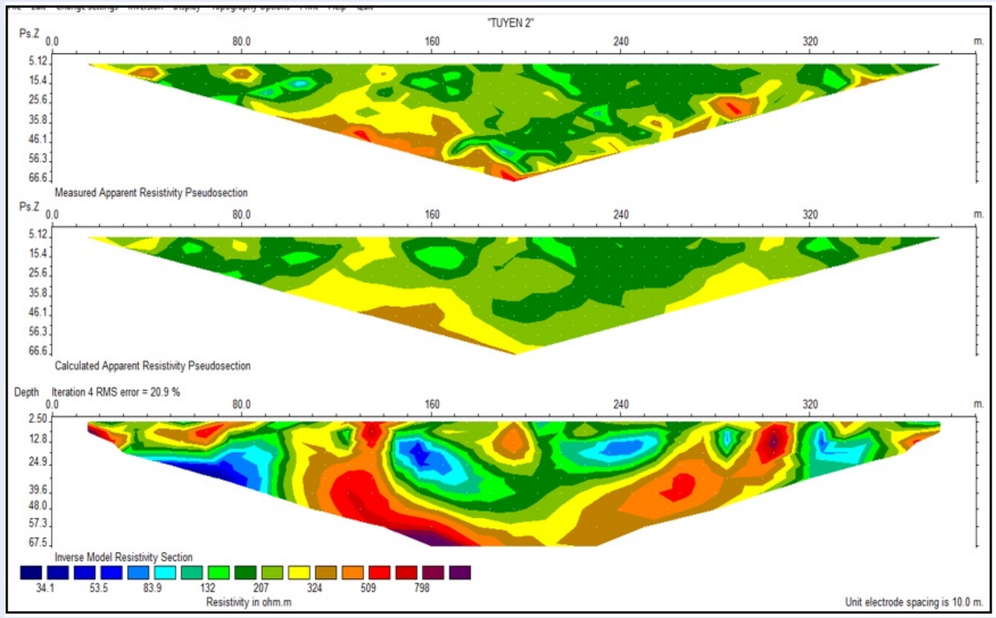

Figure 4: 2-D imaging profile of survey line No.2

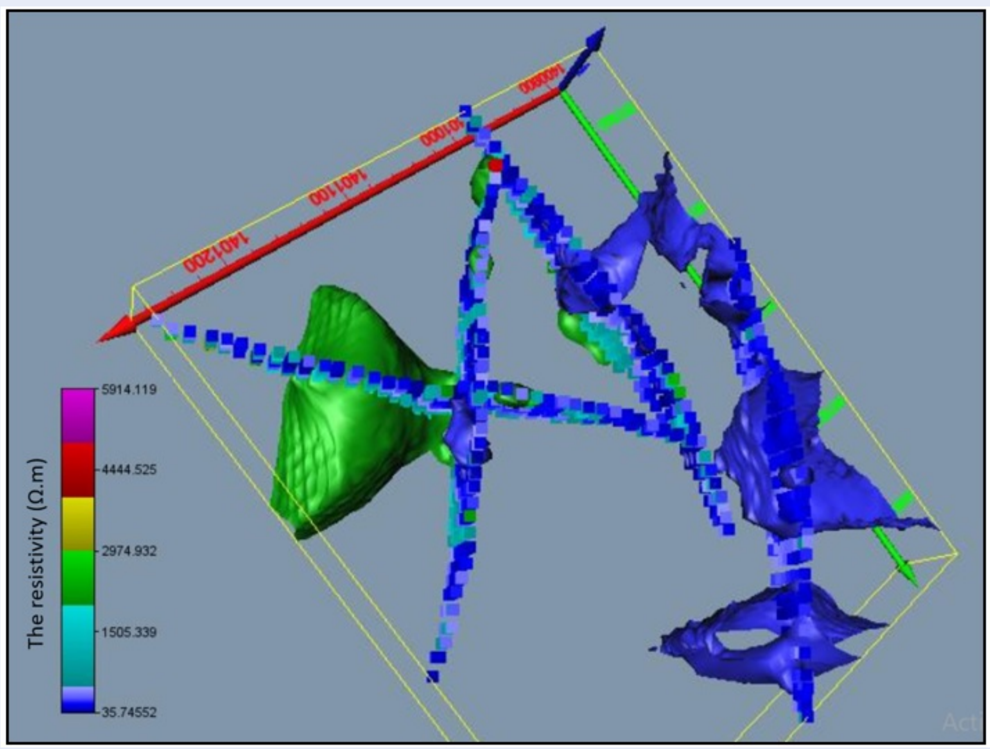

Figure 5: 3-D imaging profile of resistivity isovalue at 250 and 2240 Ω.m

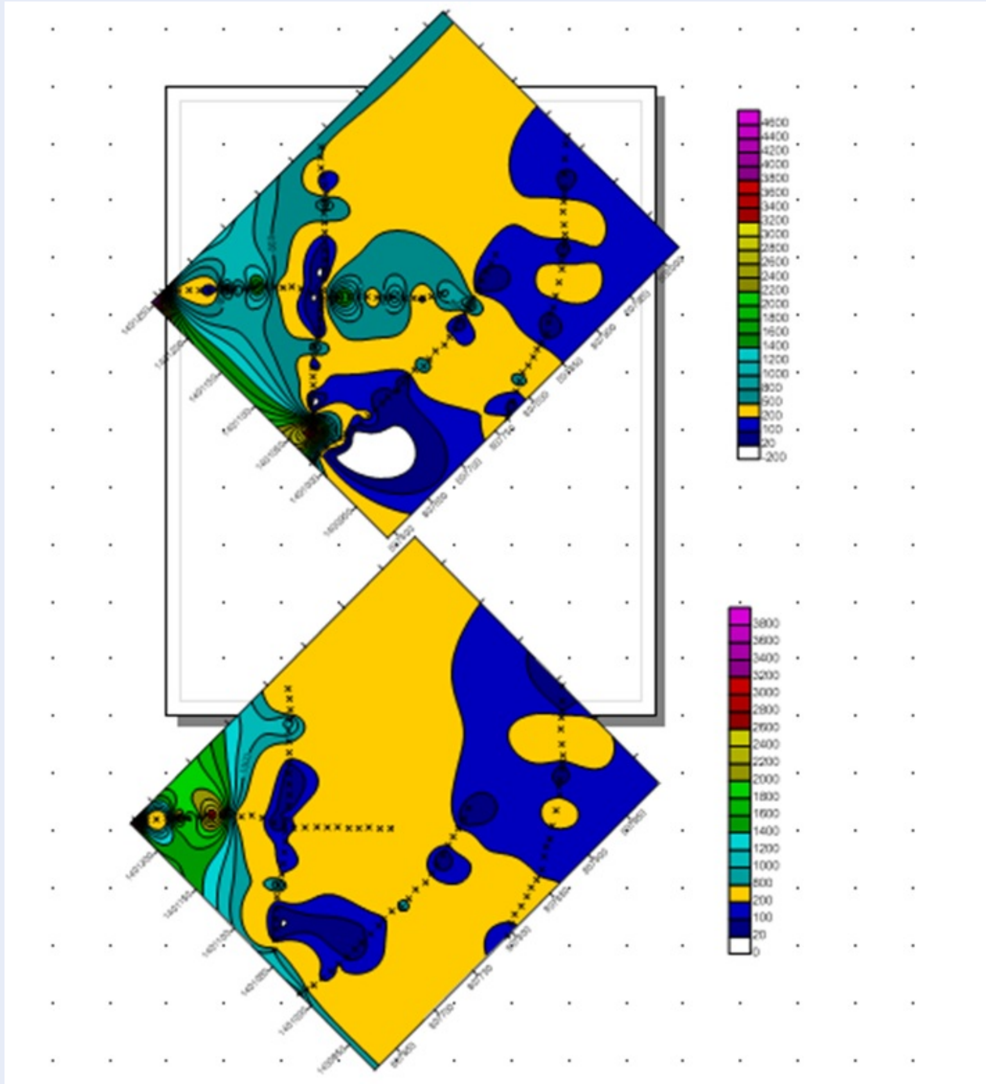

Figure 6: Iso-resistivity map of survey depth -18.5 and -24.9 meter.

to 200 Ω.m and offers moderate aquifer protective capacity. The drilling well location is also recommended from the result of the survey.

For future endeavors, we recommend conducting additional survey lines to gain a more comprehensive understanding of the survey area. Furthermore, it would be beneficial to directly observe the drilling process and draw comparisons with similar areas in order to align with best practices and guidelines.

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CONFLICT OF INTEREST

All authors declared that there is no conflict of interest in this study.

AUTHOR CONTRIBUTIONS

Conceptualization, X.K. Nguyen; Methodology, V.X. Tran; Software and Writing-original draft preparation, T.T. Nguyen; Validation, V.A. Nguyen; Formal analysis, T. Nguyen; Writing-review and editing, Q.T Truong.

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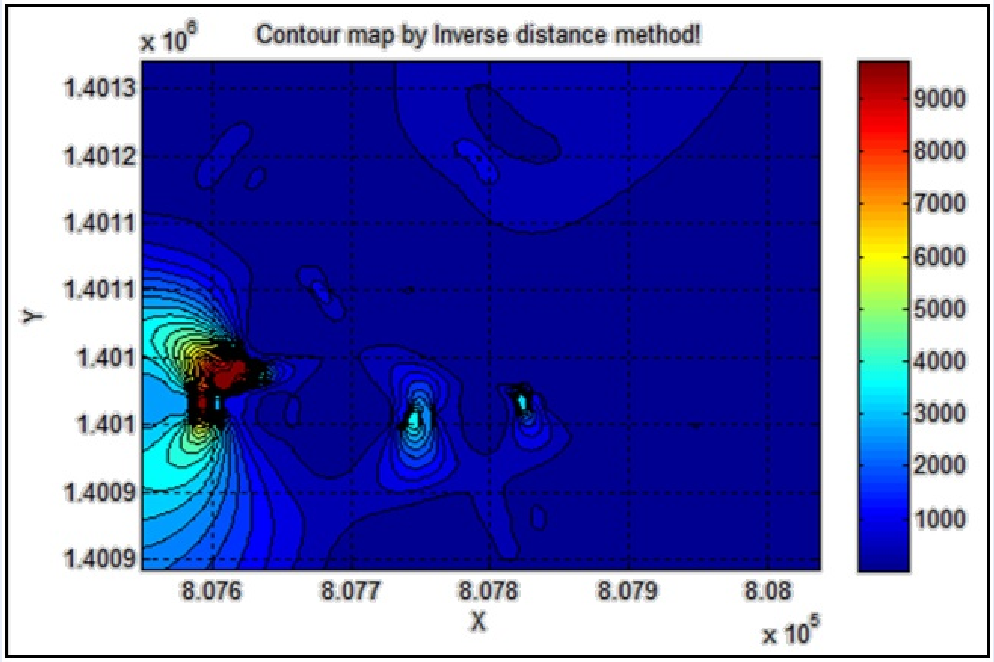

Figure 7: The resistivity contour map of layer depth -25m

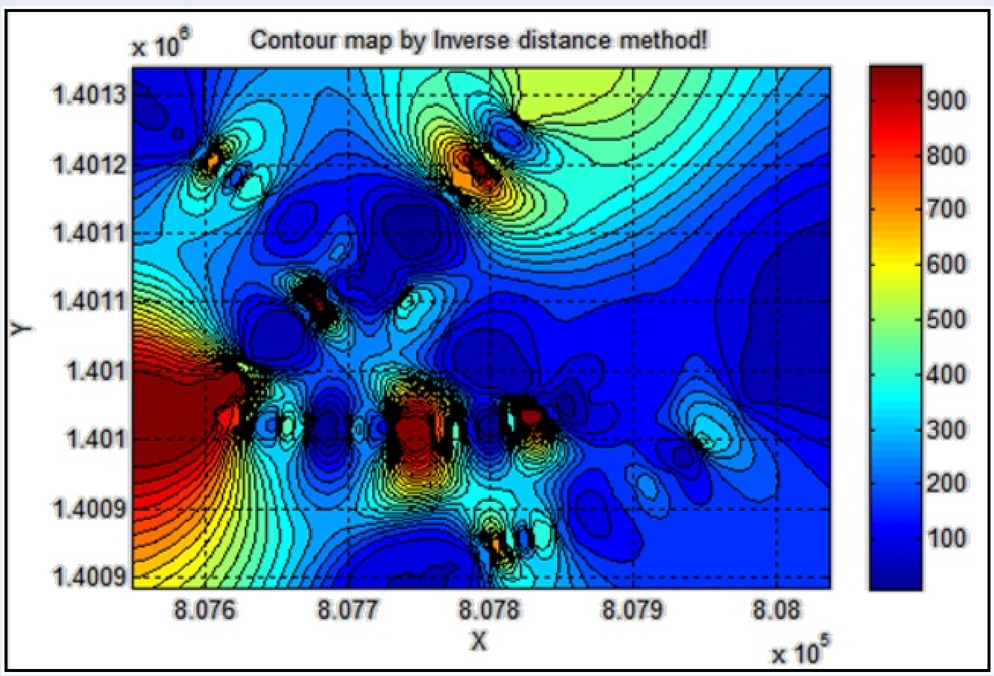

Figure 8: The resistivity contour of layer depth -25 with modify the desired values

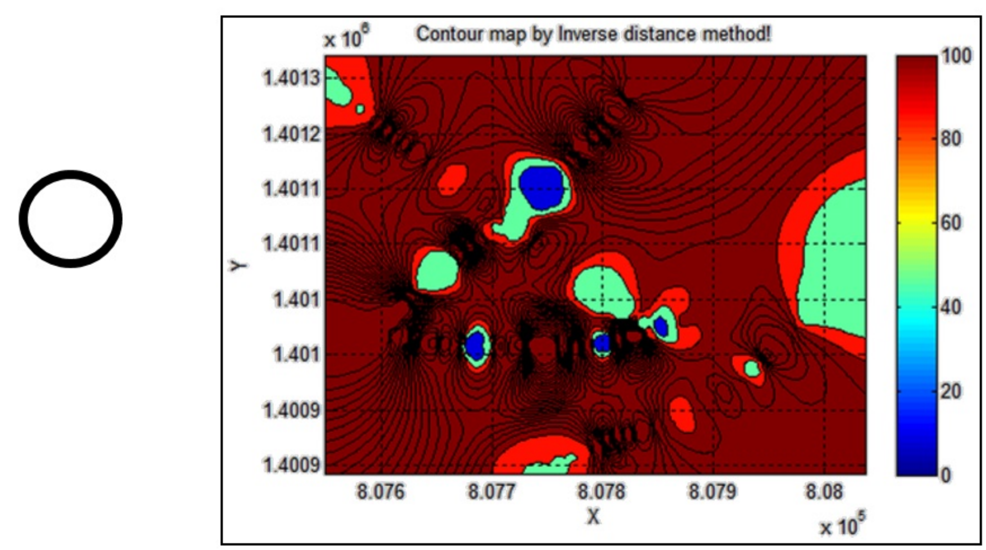

Figure 9: The resistivity contour map of layer depth -25m with modify value <100 Ω.m

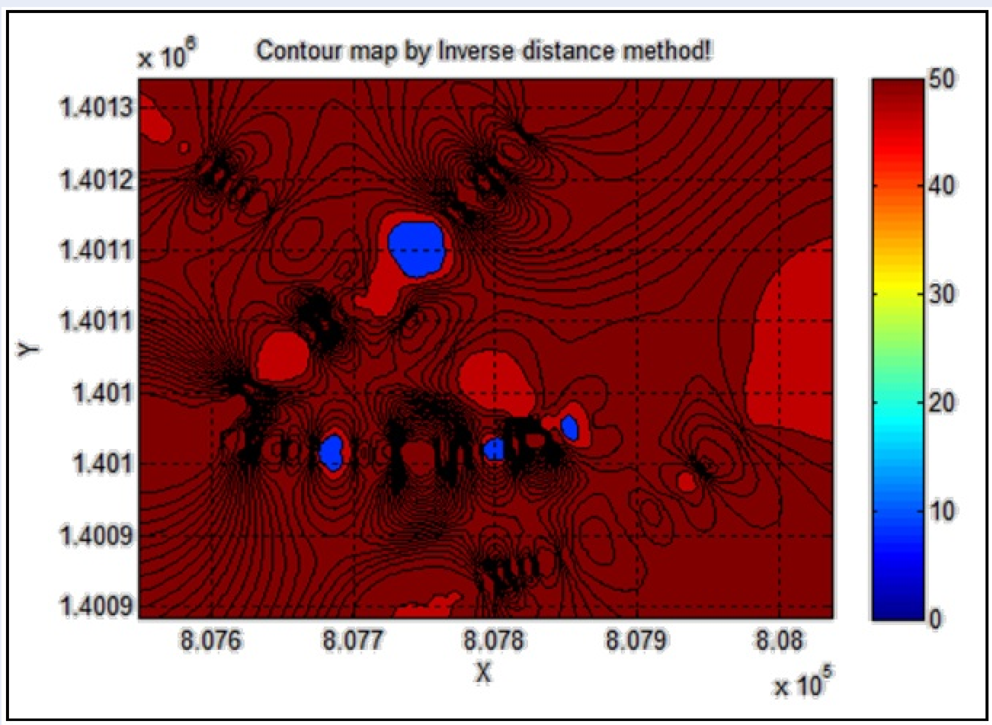

Figure 10: The resistivity contour of layer depth -25m with modify value <50 Ω.m

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Bài nghiên cứu

Đánh giá tiềm năng nước ngầm để tưới cây cà phê trong hộ gia đình bằng các thông số điện trở suất: Nghiên cứu điển hình ở Cư Jút, Đăk Nông

Trương Quốc Thanh[1,2,3,*], Nguyễn Xuân Kha[1,2], Nguyễn Trung Tín[1,2], Nguyễn Tuân[1,2], Nguyễn Việt An[1,2], Trần Văn Xuân[1,2]

TÓM TẮT

Cuộc điều tra điện trở suất được thực hiện trên một khu đất ở Cư Jut, Đăk Nông với mục tiêu là đánh giá tiềm năng nước ngầm phục vụ canh tác cà phê. Dự án với quy mô địa phương này sử dụng một cách tiếp cận toàn diện, bao gồm ba điểm đo sâu điện (VES), bốn mặt cắt điện 2-D trải rộng trên bốn tuyến khảo sát và mô hình 3D để phân tích chi tiết đặc trưng khu vực. Việc minh giải định lượng các đường cong VES đóng vai trò quan trọng của nghiên cứu, được thực hiện với độ chính xác thông qua việc khớp hóa đường cong và mô hình 1-D được máy tính hỗ trợ bằng phần mềm IPI2 win. Cách tiếp cận chi tiết này đã tạo điều kiện thuận lợi cho việc xác định bốn lớp địa chất riêng biệt trong khu vực nghiên cứu. Lớp đất bề mặt ở vị trí nông nhưng thiếu các đặc tính địa chất thủy văn quan trọng. Bên dưới lớp này, lớp bazan bị phong hóa một phần nổi lên như một đơn vị tầng chứa nước nhỏ, có độ dày thường dao động từ 10 đến 15 mét. Tuy nhiên, ý nghĩa địa chất thủy văn của nó là vừa phải. Sự sắp xếp xen kẽ của các lớp bazan xốp và chặt chẽ, tạo thành tầng chứa nước chính, đóng vai trò là một phát hiện quan trọng. Tầng chứa nước này được đặc trưng bởi các giá trị điện trở suất thường dưới 300 ohm-m, tầng chứa nước này có độ thấm và độ xốp thấp, cho thấy khả năng lưu trữ nước ngầm hạn chế. Đá móng đánh dấu lớp cuối cùng trong mặt cắt địa chất khảo sát. Tích hợp dữ liệu từ cả cấu hình hình ảnh 2-D và hình ảnh 3-D, nghiên cứu đã đi sâu vào việc đánh giá độ sâu chứa nước tiềm năng và ước tính trữ lượng. Bằng cách sử dụng bản đồ đường đồng mức, nghiên cứu cũng xác định được các vị trí tối ưu để lắp đặt giếng khoan. Kết quả của nghiên cứu chỉ ra rằng lớp bazan xốp và chặt xen kẽ là tầng chứa nước chính có tiềm năng cung cấp nước ngầm đáng kể. Ngược lại, các lớp địa chất khác được coi là có ý nghĩa địa chất thủy văn hạn chế. Đánh giá tổng thể này, các phương pháp điện trở suất tiên tiến, cung cấp những hiểu biết có giá trị cho việc quản lý tài nguyên nước bền vững, đặc biệt là trong bối cảnh trồng cà phê ở Cư Jút, Đăk Nông.

Từ khoá: đo sâu điện (VES), ảnh 2D, ảnh 3D, phần mềm IPI2 win, nước ngầm, điện cực

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