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Application of Vertical Electrical Sounding (VES) for Subsurface Profiling in Weh Island, Aceh Province

Marwan Marwan[1,*], Rifqan Rifqan[2], Idris Syafrizal[1], Yanis Muhammad[1]
[1] Geophysical Engineering Department, Universitas Syiah Kuala
[2] Geological Engineering Department, Universitas Syiah Kuala
**Corresponding author : marwan.geo@unsyiah.ac.id*

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Abstract– Groundwater availability is the main concern in a developing region such as Weh Island, Aceh. To locate groundwater resources, vertical electrical sounding (VES) was used to identify subsurface profiles. The study area is located on a volcanic island. The lithology consists of volcanic rocks as andesite lava and pyroclastic rocks as lapily-tuff until breccia. VES method was carried out in 4 measurement points using the Schlumberger array. The resistivity value used to identify subsurface lithology. The top layer of alluvium and weathered lava have resistivity ranges from 14.3 Ωm to 17.7 Ωm with thickness varies from 0 m – 17.4 m. It is followed by andesite resistivity ranges from 17.3 Ωm to 18.2 Ωm with averages thickness is 17.4 m – 35.2 m. Finally, the bottom layer is filled by breccia-tuff with resistivity value from 5.5 Ωm to 7.3 Ωm. The physical properties of some related rocks allow water accumulation to their bodies. The current polarization indicates water content in the pore space of breecia at the study area which polarization point is identified as the water table.

Keywords: VES, subsurface profiling, lithological correlation, current polarization, water table.

Introduction

Weh Island is a rapidly developing area in the Aceh province; the island has been promoted as a tourism region. Moreover, the foreign tourists that visiting the island is more 80 thousand for every year, so that it will be an automatic increase in the rate of groundwater usage graphics. Besides, the availability of fresh water on the island surrounded by brine water is limited. The groundwater is the water lies underground and held in the subsurface and controlled by terrain and landforms. (Erwin, *et al.*, 2015). The groundwater can exist in the sedimentary terrain where it is less difficult to exploit or in crystalline rocks that it can be a bit difficult to locate it (Abdullahi *et al.*, 2015). In another case, the study area is nearby of the geothermal resource; Jaboi Volcano (seen in Figure 1) that has been explored and need to be developed which the availability of the groundwater resources is really important. For this reason, the efforts that related to the development and conservation of groundwater supplies are fundamental economic interests for developing of Weh Island.

In purpose to identify groundwater resources, the application of modern geophysical methods is more effective in finding the water-containing formations. In terms of time-consuming, the geophysical method is relatively fast and simplicity used, but for more comprehensive result, the technique of the integrated geological and geophysical interpretation is rarely used; namely Sultan *et al.* (2015) used resistivity method for delineating groundwater and subsurface structures and Sundararajan *et al.*, (2012) used for resistivity and lithology analysis. The analysis also combined with geological data of the area. VES method also used by Abdullahi, et al., (2015) for groundwater prospecting using Schlumberger array system and Kola *et al.*, (2013) for identifying aquifer units and sedimentary environment. It presents the geological profile sequence by interpreted apparent resistivity. VES method has become a very popular technique because of its simplicity. It also used by Hassan *et al.*, (2017) and Kumar *et al.*, (2012) to understand groundwater potential by identifying subsurface layers and grouping into weathered and fractured layers. The analysis also compared to the current geological study by Rifqan (2018) who collected geological data around the study area. Lithology and structures are the main concerns of additional analysis.

The electric current properties that generated form geoelectric instrument have limited utilization in sub-profile analyzing saturated by water. In the present work, the author carried out to identify water table depth and create a 2D lithological model for estimating the subsurface layers as the groundwater zone.

Materials and Methods

In understanding Jaboi's groundwater system, geological and geophysical observation are used for creating an integrated model. Geological observation is focused on morphology and potential lithology as an aquifer. The terrain of study area observed by studio-analysis using ArcGIS and Surfer. Previous research such as geological mapping also founded as additional data.

To create a subsurface model, vertical electrical sounding (VES) is used as a method to identify the subsurface profile and presented in the 1D graphic. Data collection carried out for 4 measurements points with 250 m space one to another point and Schlumberger array. The 1D model has been created based on the RMS error value gained from EARTHIMAGER1D software. SuperSting Resistivity meter R8/IP is the instrument used for data collecting at the field.

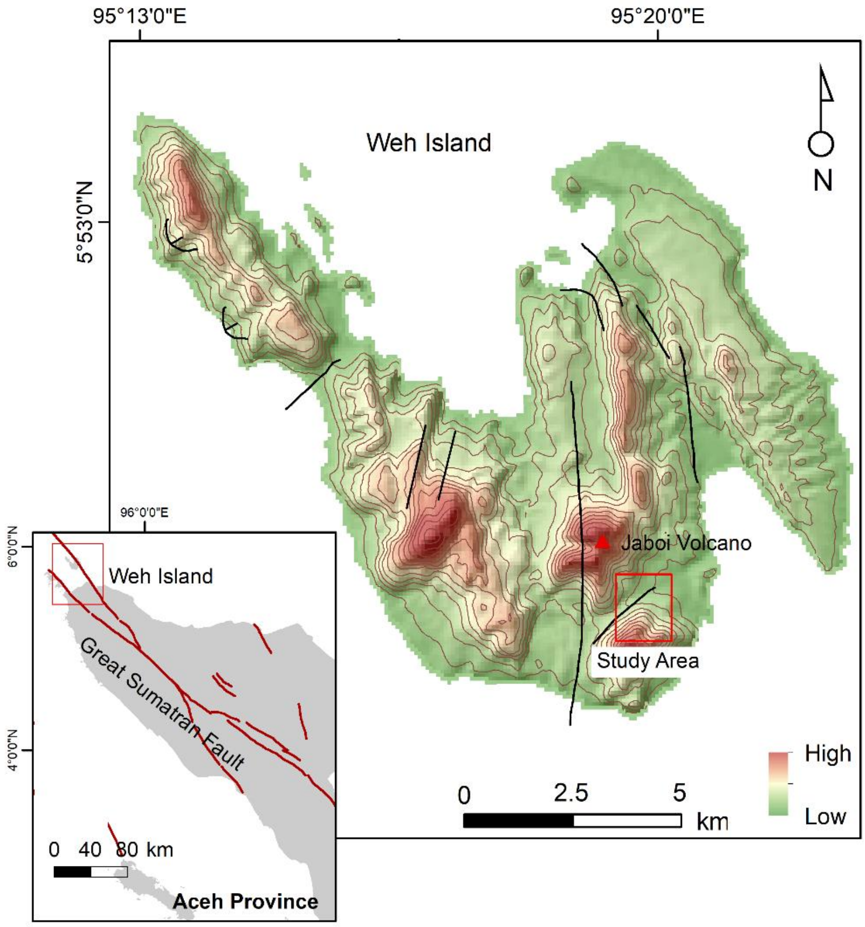

Figure 1. Map of Weh Island shows Jaboi Volcano. The study area is nearby of the geothermal resource. The fault structure from geological maps is shown by a black line.

Results and Discussions

Geology of Study Area

Geomorphology of the study area consists of 3 volcanic landforms cone, upper volcanic slope, and lower volcanic slope (Rifqan, 2018). Volcanic cone covers 10% area incudes Leumo Matee's peak, Keunalo's peak, and Semereguh's peak. Upper volcanic slope includes Leumo Matee's upper slope and Semereguh's upper slope and dominated by andesite rocks. Weh's lower slope covers 60% of the study area and dominated by breccia and lapiliy-tuff. Study area located at 40 – 60 meters above mean sea level or at flat-ramps land. The area surrounded by volcanoes terrain, they are Leumo Matee, Keunalo and Semereguh (650 m) with the flow pattern type is multiracial. By different altitude, the study area is divided by 4 zones can be seen in Figure 2. First, peak zones, In this area absorption ration are very low. Second, an old volcanic zone that has a medium slope. In this area fracture rocks have a big role in water absorption. Water accumulation started in this zone. The third is breccia until tuff area; this area also consisted of weathered materials from upper terrain. It causes some thin layer in this area to become alluvium. Fourth, it is low terrain zone as fluvio-volcanic area and can be found small season river.

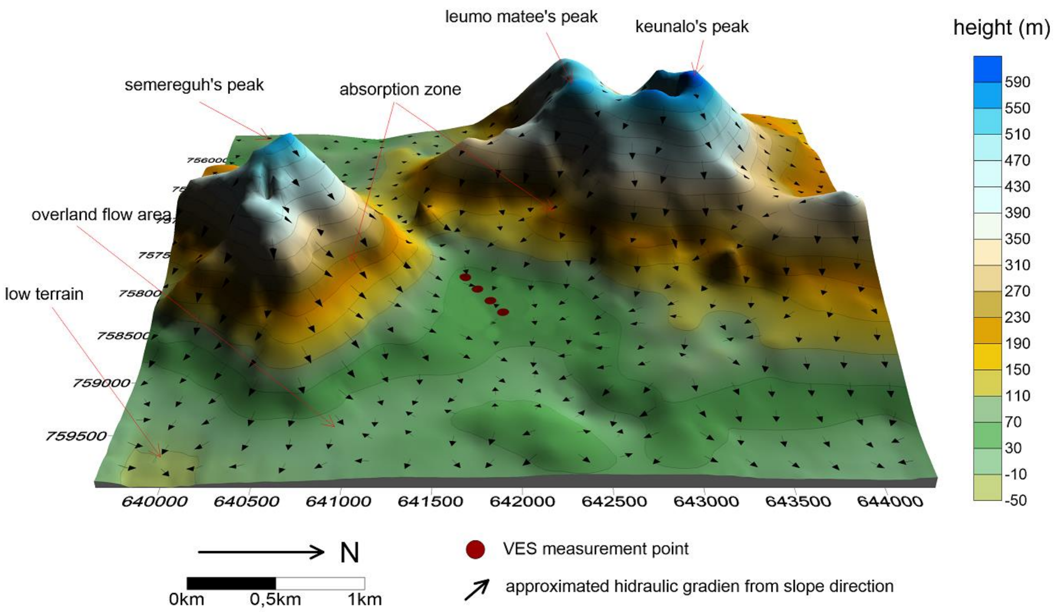

Figure 2. Overview of zone classification of the study area which is bounded by high terrain volcanoes.

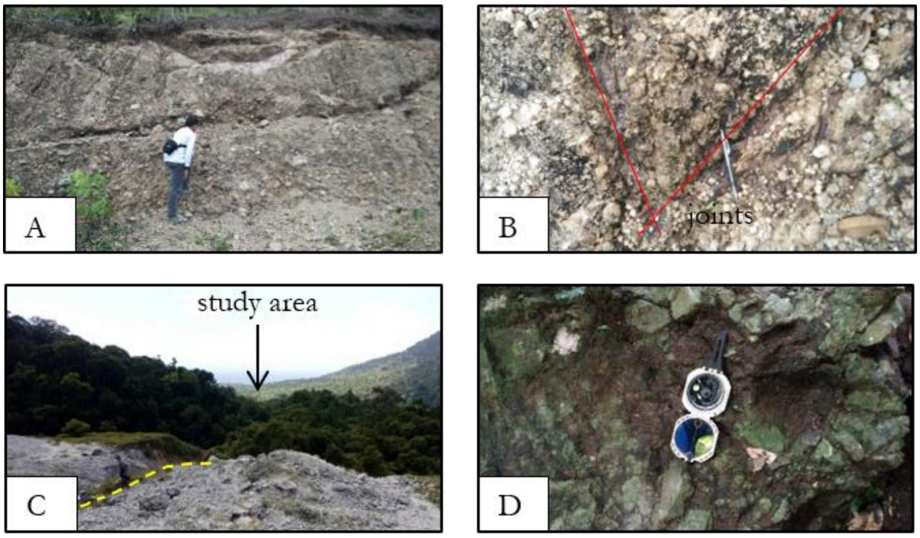

Figure 3. (A) Outcrop of breccia - tuff covers high terrain at the area of East and along North-South of the study area. (B) Existed joints of breccia yield amount of meteoric water located at several areas that indicated absorption zones. (C) Present alterated rocks of Leumo Matee's peak and distribute andesitic lava into low terrain of the study area. (D) Complex fractured andesitic rock of Semereguh also recognized as a part of absorption zone.

The geological structures of the study area consist of several trends. Major fault structures have NW-SE direction that means its strongly affected by Sumatran fault, especially by Seulimum segment. These structures have developed and triggered some local faults such as Leumo Matee and Ceunohot fault that are

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included in the study area. The activity of Great Sumatran Fault (GSF) also initiates volcanic-born in Weh Island, the GSF is a parallel strike-slip arc along the volcanic front that stretches alongside of 1900 km from the southern of Sumatra to the Andaman Sea (Ismail et. al, 2016). Most of the volcanoes are composed of complex volcanic products during the Quaternary period. Based on geological data, the lithology composed by Lava and pyroclastic rocks. It covers the whole study area which the oldest unit is from Weh's Pyroclastics that consist of breccias and lapily tuff.

The volcanic units are produced by some strato-volcanoes such as Leumo Matee, Keunalo, and Semereguh. Extrusive volcanic rocks founded as andesitic lava of Leumo Matee on the west of study area with porphyritic texture. On the south, it is founded darker andesitic lava. Some of the lava's body was fractured. The youngest pyroclastic rocks layered upper Leumo Matee's lava as volcanic breccia composed by bright tuff-sand as the matrix, andesitic fragments, and good porosity, for more details see Figure 3.

VES Analysis

Vertical electrical sounding data show contrast resistivity each point measurement by depth. The contrast exists because of lithological composition difference. Each layer influenced by volcanic products sequence during the Quaternary period. Generally, trends of VES data indicate the same result. High and low resistivity value are separated by an average value in the middle of layers as shown in Figure 4. VES method carried out at 4 point measurements. Each measurement point has 250 m space one to another. Based on the 1D model of S-7 section, the range of resistivity has 5.5 ohm-m as a minimum value and 436.3 ohm-m as the maximum value. On that range, resistivity changing is fluctuative-smooth. The changing trend of resistivity value occurred at 15-20 m by depth. The trend also showed by other sections that correlated; they are, S-3, S-11, and S-12 with small depth difference.

By generated data, the inverse model is created. For example, S-7 section presents three general layers, they are The alluvium and weathered lava ranges from 14.3 Ωm to 17.7 Ωm with thickness varies from 0 m – 17.4 m. Andesite ranges from 17.3 Ωm to 18.2 Ωm with thickness averages ranges from 17.4 m – 35.2 m. And breccia-tuff resistivity ranges in value from 5.5 Ωm to 7.3 Ωm with unspecified maximum depth.

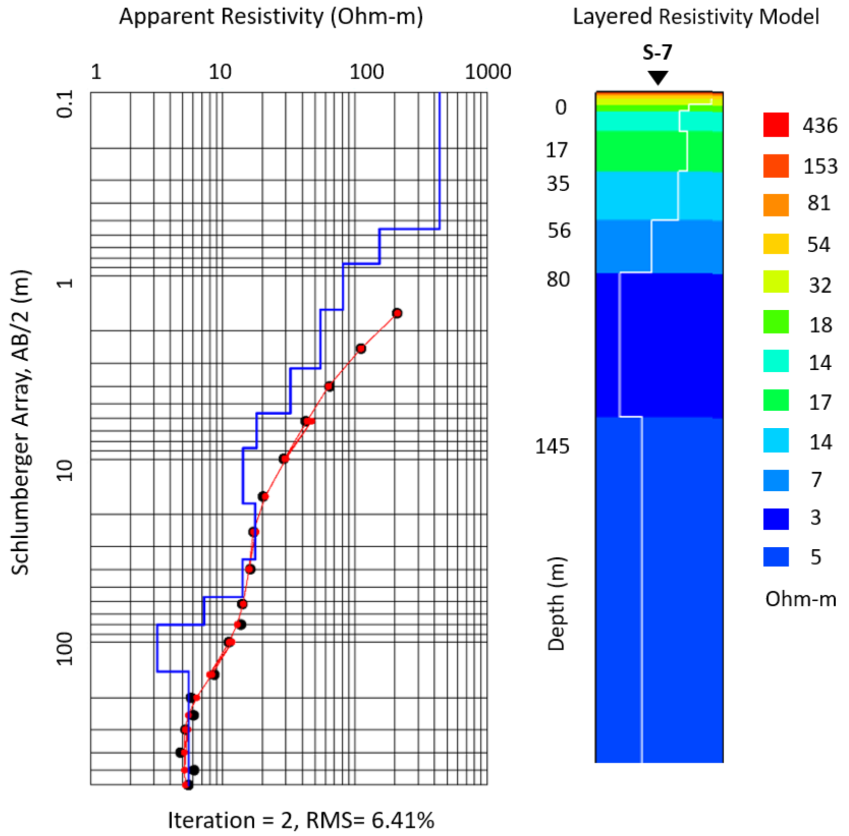

Figure 4. VES inversion model of S7 line. The contrast resistivity showed by different lithology. The RMS error of the model and data observed obtain to 6.41 % in two iteration that can be indicated as the quality of the data is really good.

Based on morphology condition, alluvium exists in low terrain. The materials can be supplied by higher terrain (surrounded volcanoes). The erosion process also works on lava body. Therefore, small step increase of resistivity value after alluvium. This condition is not specified and grouped as one layer. Another fresh lava body lies beneath the weathered one and increases resistivity value (green zone). This fluctuation trend also happened on other VES sections. The decreasing resistivity value (blue zone) indicate the change of lithology. In this case, conductivity properties caused by water content in a rock body, the possible type of rocks in the last layer is breccia which is outcrops in the study area. The physical properties such as less dense, poor sortation and well saturated are founded.

In another case, water content polarizes electric current caused unspecified depth identification of the model. Then this polar-point is identified as a water table. By considering fault structures, some line section across the structures to understand resistivity change because of Ceunohot fault (NE-SW). By S-7 model, a thickest low-resistivity layer showed at 80 ~ 300 m. This condition identified as water accumulation supported by Ceuohot fault (NE-SW) as crack porosity as shown in Figure 5A. Furthermore, the current polarization means the depth of the water table in the study area. Based on the smallest RMS error value, resistivity correlation created and compared to geological data. The resistivity value indicates the specific physical properties of rocks. In this case, porosity contained water give a significant effect on resistivity change. Based on porosity properties, Lithological identification and correlation created, for more details see Figure 5A. Geological data shows topographic condition and correlated lithology.

Three layers indicate the same trend with different thickness. Grey layer indicates the alluvium and a weathered layer of lava. Each section has different thickness because of different elevation and erosion grade. The red layer shows fresh andesite layer which has been faulted. This condition also has triggered hot water exists to the surface. The last layer is filled by breccia with unspecified depth. The thickest unit of breccia possible occurred because it is the oldest unit of the study area.

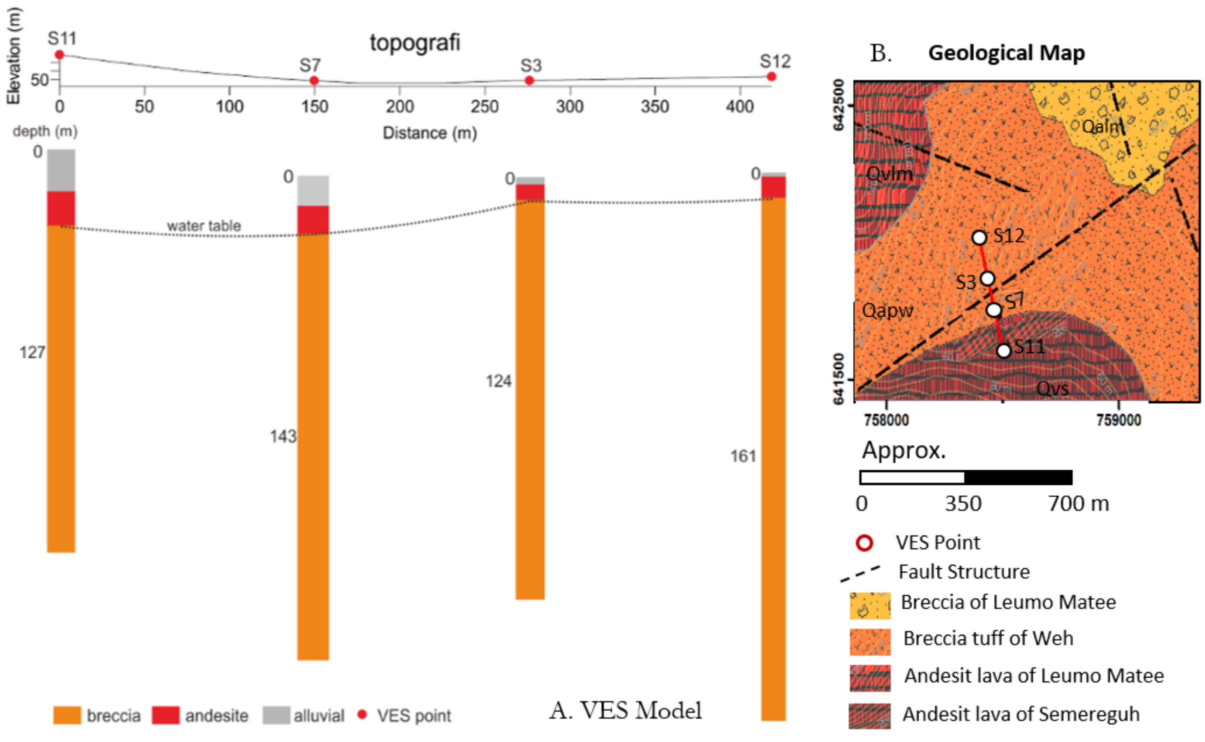

Figure 5. (A) The line section across major fault structure where groundwater is accumulated. Lithological correlation of VES model analysis (B). The line section generated topographically and correlated by the water table of the study area.

Correlation analysis also compared to geological data. Lithological distribution consisted of volcanic and pyroclastic rocks, give contrast resistivity value for VES section. Andesite as extrusive rocks has low porosity and permeability. But in this case, it can be changed by active structures. Andesite correlation carried out by resistivity value that has the same pattern with other point measurements. Other rocks correlation show breccia as the potential aquifer. The trends of VES section indicate the same resistivity change after massive andesite. This condition supported by breccia's matrix composed by sand and tuff and andesite rocks as a fragment so become intergranular porosity. By referring geological data, local fault structures named Ceunohot fault also contribute to water accumulation and permeability zone. It connected some minor faults occurred.

Conclusion

Vertical electrical sounding data show contrast resistivity each point measurement by depth. The lithology consists of volcanic rocks as andesite lava and pyroclastic rocks as lapily-tuff until breccia. The top layer of alluvium and weathered lava have resistivity ranges from 14.3 Ωm to 17.7 Ωm with thickness varies from 0 – 17.4 m that followed by andesite resistivity ranges from 17.3 Ωm to 18.2 Ωm with averages thickness is 17.4 – 35.2 m. The bottom layer is identified as breccia-tuff with resistivity value from 5.5 Ωm to 7.3 Ωm. Lithology distribution can be clearly identified in the form of volcanic and pyroclastic rocks of measured resistivity values. Andesite correlation carried out by resistivity value that has the same pattern with other point measurements. Other rocks correlation show breccia as the potential aquifer that also confirmed by geological data. Profiles of VES section indicate the same resistivity change after massive andesite. This condition is supported by a breccia matrix composed of sand, tuff and andesite rocks as fragments so that it becomes intergranular porosity.

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