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RESEARCH ARTICLE

UTILIZATION OF RESISTIVITY DATA TO ESTIMATE THE DEPTH AND THICKNESS OF ANDESITIC LAVA DEPOSITS AS FRACTURED AQUIFERS IN PADAMARA DISTRICT, PURBALINGGA REGENCY, INDONESIA

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ABSTRACT

Resistivity data acquisition using the Vertical Electrical Sounding (VES) technique has been carried out in Padamara District, Purbalingga Regency, Indonesia. The research purpose was to obtain data on the depth and thickness of lava deposit formations which are estimated to function as fractured aquifers. The data acquisition results in the field were subsurface rock resistivity data spread at five sounding points with values ranging from 0.69 – 260.41 Ωm. The sounding points were located at the geographic position of 7°22′41.77" and 109°17′54.03" to 7°22′41.77" and 109°20′35.47". The resistivity data interpretation results were lithological logs at each sounding point, while correlation result between lithological logs was a hydrostratigraphic cross-section model. Based on this model, the stratigraphy of the research area was composed of top soil (0.69 – 61.23 Ωm); interbedded clay, silt, and sand (13.05 – 49.14 Ωm), laharic deposits of Slamet Volcano (114.69 – 260.41 Ωm), lava deposits with many cracks, fractures, and small cavities (64.31 – 94.55 Ωm), tuffaceous sandstone (25.59 – 39.14 Ωm), sand and tuff (8.37 – 20.32 Ωm). The aquifer conditions in the research area could be classified into three types, that are shallow aquifers in the Alluvium Formation, intermediate aquifers in the form of fractured aquifers in the Lava Formation, and deep aquifers in the Undak Formation. The results of the research show that the depth of andesitic lava deposits that function as fractured aquifers ranges from 3.31 – 136.90 m from the topographical surface, while the thickness ranges from 12.78 – 71.10 m.

KEYWORDS

Resistivity data, Depth and thickness, Fractured aquifer, Padamara District.

1. INTRODUCTION

Groundwater is one of the main links in the hydrological cycle on Earth. Groundwater comes from rainwater that seeps into the soil and rocks thru pores, cracks, and fractures in the recharge area. Groundwater flows and is stored in small open spaces between rocks, sand, soil, and gravel in the subsurface called aquifers. The aquifers are generally located in the discharge area of a basin. A groundwater basin is a basin area bounded by hydrogeological boundaries, all hydrogeological events take place within it such as recharge, flow, and discharge of groundwater (Zeffitni, 2011). Groundwater has an important role to maintain the balance and availability of freshwater for agriculture, farming, industry, tourism, livestock, households, and others. One of the groundwater basins in Central Java that is prospecting further geophysical study is the Purwokerto–Purbalingga Groundwater Basin since this basin is one of the largest groundwater basins in Central Java with an area of about 1,318 km^2 (Ramadhan, 2020). This basin is estimated to contain large amounts of groundwater. The obtained results from this study are very useful for supporting programs to provide freshwater for the community and the development of groundwater-based agricultural irrigation program.

One way to utilize water sources in groundwater basin areas is through the construction of wells, both shallow wells and deep wells. Well is one of the sources of fresh water that is commonly utilized by the community for daily needs. In addition to shallow and deep aquifers, well water sources can come from fractured aquifers, which are generally found in volcanic rocks with many cracks and fractures. One area in Indonesia that has the potential for fractured groundwater is Padamara District, Purbalingga Regency, Central Java which is part of the Purwokerto-Purbalingga Groundwater Basin. This research area acts as a connecting zone between the recharge area on the upper slopes of Slamet Volcano and the discharge area that stretches between Purwokerto City and Purbalingga City, Central Java, Indonesia (Sehah et al., 2024). Based on geological information, the research area is composed of alluvial deposits, laharic deposits of Slamet Volcano, and andesitic lava rocks with many cracks and fractures (Djuri et al., 1996).

In 2023, study on the potential of the Purwokerto-Purbalingga Groundwater Basin was carried out by the author (Sehah et al., 2023). The data used comes from GGMPlus with 51,900 sets of gravity anomaly data spanning the geographical position of 109.008° – 109.608° E and 7.255° – 7.603° S. After going through several stages of processing and modeling gravity anomaly data, a distribution model of subsurface rock density was obtained with values ranging from 1.2 – 4.8 g/cm^3 (Sehah et al., 2024). Based on this model, the basin area was interpreted to be composed of alluvial with densities ranging from 2.10 – 2.55 g/cm^3 and depths of more than 4 km, whereas the northern edge was composed of volcanic rocks (Sehah et al., 2024). The results of the study have provided an important stage in the development of the Purwokerto-Purbalingga Basin area as a potential source of groundwater for agricultural irrigation and living needs. The recommended follow-up is exploration of groundwater sources using the resistivity method in several locations, including the northern area of Purwokerto–Purbalingga Basin. This research aims to obtain data on the depth and thickness of lava rock formation of Slamet

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Volcano which act as fractured aquifers so that the results provide a positive contribution, especially in the provision of fresh water in the research area.

2. Literature Review

2.1 Geoelectric Resistivity Method

Geoelectrical resistivity is one of the subsurface geophysical exploration techniques based on the distribution of resistivity properties of subsurface rocks. Electrical resistivity is one of the physical characteristics of every object, so technically its value can be used to identify types of subsurface rock. Geoelectric methods are widely applied for the estimation of subsurface geological structures and exploration of various natural resources; such as groundwater (Ugwu et al., 2016), geothermal resources bedrock layers, ground movements and landslides and other geophysical exploration or geological structures (Ramadhan et al., 2022; (Syamsuddin et al., 2021; Wakhidah et al., 2014). The resistivity data acquisition method is carried out by injecting direct electric current (DC) into the earth through two current electrodes at points C_1 and C_2 such as Figure 1. The electrical current injected into the Earth will be distributed through the medium of soil and rock.

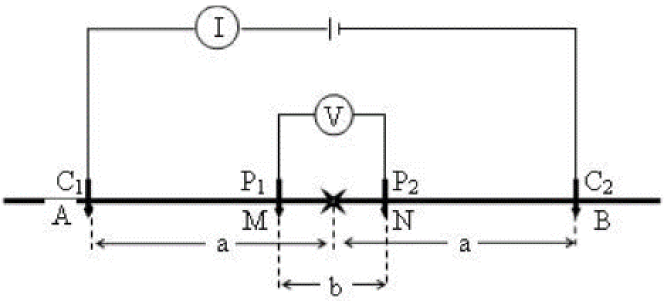

Figure 1: Electrode arrangement schematic in geoelectrical resistivity data acquisition.

After the electrical current spreads, the electrical polarization which occurs in the rock medium is measured by the difference in potential through two potential electrodes at points P_1 and P_2. After the electric current and the potential difference are measured, the apparent resistivity value for each subsurface rock layer is obtained based on the equation (Telford et.al., 1990).

$$\rho_a = K\frac{\Delta V}{I} \tag{1}$$

where ρ_a is the apparent resistivity, ΔV is the potential difference, I is the electric current and K is the geometric factor whose value depends on the configuration of the electrode distance. The apparent resistivity value of each rock layer is then modeled in forward and inversion so that the true resistivity for each rock layer is obtained. These true resistivity values are interpreted to determine the type of lithology of each subsurface rock layer, including their depth and thickness (Khalil and Santos, 2013).

2.2 Geologial Setting

Geological maps and information show that the Purwokerto-Purbalingga Basin occupies a basin-shaped area in the middle of Java Island known as the Serayu Valley. This valley separates the North Serayu Mountains and the South Serayu Mountains. This basin stretches from west to east through few regions and cities such as Majenang, Ajibarang, Purwokerto, Banyumas, Purbalingga, Banjarnegara, and Wonosobo (Bammelen, 1949). The research area consists of several stratigraphic units, as seen on the Geological Map in Figure 2 (Djuri et.al., 1996; Asikin et.al., 1992; Condon et.al., 1996). The alluvial deposits that fill this basin are estimated to originate from millions of cubic meters of sedimentary material carried by river flows due to geomorphological processes which are affected by exogenous factors, such as wind, climate, rainfall, temperature, and several other factors. The materials were then deposited in the basin for millions of years, giving rise to thick alluvial deposits (Bammelen, 1949).

Beneath the alluvial deposits are lava deposits of Slamet Volcano that are composed of boulders of andesitic-basaltic volcanic rock. Meanwhile, in the next subsurface layer, there are andesitic lava deposits composed of Slamet Volcano lava with many cracks and fractures (Djuri et al., 1996). Figure 2 shows that both rock formations are exposed in the northern part of the groundwater basin. The aquifer in this region is estimated to be a fractured aquifer type. Groundwater originating from the recharge area will flow to the discharge area through this fractured aquifer. Resistivity surveys were carried out at several locations in the area (as seen in Figure 2) to estimate the depth and thickness of the lava rock deposits which are likely to contain groundwater.

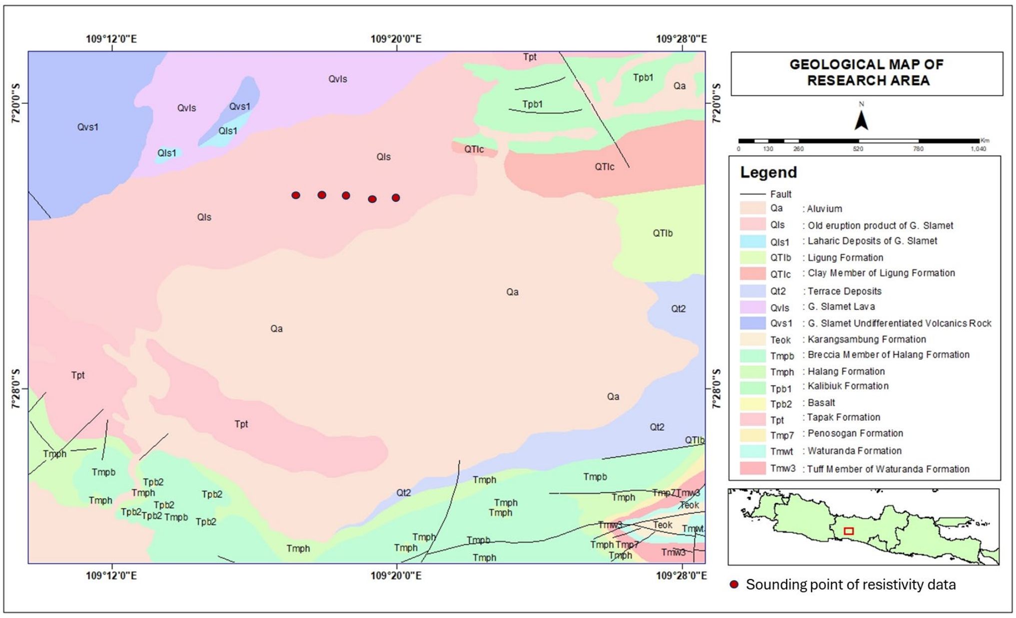

Figure 2: Geological map of the research area; resistivity data acquisition was carried out at the Slamet Volcano Laharic deposits the resistivity data sounding points are marked with red dots, sequentially from Sch-1 (far left) to Sch-5 (far right) (Djuri et al., 1996).

3. Research Method

3.1 Location and Time of Research

Resistivity data acquisition was carried out in the Padamara District, Purbalingga Regency, Central Java, Indonesia. The research area is included in the Purwokerto–Purbalingga Groundwater Basin area. Resistivity data acquisition was carried out at five sounding points, with the position of each sounding point shown in Table 1. Processing and modeling of resistivity data were carried out in the Geophysic Laboratory, Physics Department, Faculty of Mathematics and Natural Sciences, Jenderal Soedirman University. This research has been carried out for 6 (four) months, i.e. March – August 2024.

3.2 Research Equipment

The main equipment used in the research was the Naniura NRD-300 Resistivitymeter. It was used to measure the subsurface rocks resistivity values at all location points. This equipment is equipped with 2 steel electrodes, 2 copper electrodes, 12V battery, 2×200m current cables, 2×50m potential cables, and 4×100m rollmeters. Softwares used in processing resistivity data include Progress 3.0, Surfer 17, and Microsoft Excel. The Progress 3.0 was used to model the resistivity data so that the resistivity logs are obtained at each sounding point, while Surfer 17 was used to reconstruct a lithological log model based on the interpretation results, and correlating some resistivity logs to form a hydrostratigraphic cross section (Sehah et al., 2021).

Table 1: The position of each resistivity data sounding point

No.	Sounding Point	Geographic Position	
1	Sch-01	7.3783 S	109.2983 E
2	Sch-02	7.3771 S	109.3094 E
3	Sch-03	7.3773 S	109.3233 E
4	Sch-04	7.3798 S	109.3344 E
5	Sch-05	7.3783 S	109.3432

3.3 Research Procedure

The data acquisition technique used in this study was Vertical Electrical Sounding (VES). The VES technique was carried out by varying the distance between electrodes C_1 to P_1 and C_2 to P_2 as can be seen in Figure 3. Initially, the spacing between each electrode were made the same, for example *a*. In subsequent measurement, the span of electrode C_1 was widened relative to P_1, while the span of electrode C_2 was widened relative to P_2, and so on. Thus resistivity data acquisition can cover the all research area. The distance between two potential electrodes (P_1 and P_2) in the field can be gradually widened if the distance between the current electrodes (C_1 and C_2) was far enough (Lutan, 1981). Variations in the distance between current and potential electrodes were carried out to obtain subsurface rock structure and depth data based on 1D-vertical resistivity data. The further the distance between the electrodes, the deeper the information about subsurface rocks and their geological structure (Zuhdi and Habiburrah man, 2021).

The resistivity measured in Equation (1) was not the actual resistivity value but the apparent resistivity value. The apparent resistivity value depends on the spacing distance between the electrodes, the heterogeneity of the rock medium, and physical characteristics such as metal and water content, temperature, mineral comp osition, permeability, texture, geological age and other (Simpen, 2015). The resistivity data was then processed to obtain a curve of apparent resistivity (ρ_a) versus electrode span distance (½AB). The apparent resistivity curve was used as a basis for obtaining true resistivity data for each subsurface rock layer via forward and inversion modeling. This modeling produced a curve of true resistivity versus spacing distance ½AB; and subsurface rock resistivity logs against depth. Interpretation was carried out on resistivity log data to obtain a lithological log model that described the types of rock filling each subsurface layer, equipped with true resistivity values, depth, and formation.

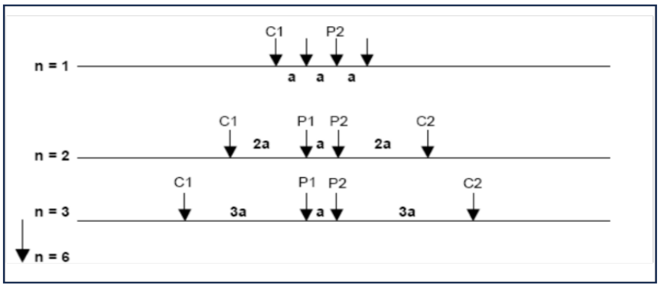

Figure 3: Resistivity data acquisition scheme uses VES technique at a sounding point.

4. Results and Discussion

4.1 Results of Processing Data

Padamara District, Purbalingga Regency, which is the location for the resistivity survey, is located above the Slamet Volcano Lahar (Qls) Formation which consists of laharic in the form of boulders andesitic-basaltic igneous rock. Under the laharic deposits, there is the Slamet Volcanic Lava Formation (Qvls) in the form of andesitic lava rock with many fractures. In the southern of the research area, there is the Alluvium Formation (Qa) in the form of alluvial deposits composed of gravel, sand, silt and clay; that are river and coastal deposits with depths of up to 150 m (Djuri et al., 1996). The research area is a connecting zone between the recharge area on the Slamet Volcanic Slopes and the discharge area to the south of the research area, which is part of the Purwokerto-Purbalingga Groundwater Basin. Groundwater is estimated to flow through cracks and fractures in andesitic lava deposits that form fractured aquifers in the volcanic rock complexes.

Data obtained in the field were current strength (I), voltage (ΔV), and spacing between electrodes. These data were processed, so that geometric factor (K) and apparent resistivity (ρ_a) were obtained for each measurement (Lubis, 2017). The apparent resistivity data was modeled using Progress 3.0 to obtain resistivity curves and logs for each sounding point. Next, the resistivity log was interpreted to obtain a lithological log that indicates the stratigraphic sequence of subsurface rocks in the area. The modeling and interpretation results were presented in the form of resistivity curves and lithology logs. For example the Sch-1 sounding point is shown in Figure 4. Lithological interpretation of the obtained modeling results is based on the Geological Map as shown in Figure 2 (Djuri et al., 1996). Based on the interpretation results, the laharic deposits were estimated to be found in the Sch-1, Sch-2 and Sch-3 sounding points with resistivity values of 114.69 – 160.41 Ωm. Mainwhile andesitic lava was estimated to exist at entire sounding points in the research area with resistivity value ranges of 64.31 – 94.55 Ωm. The resistivity value of andesitic lava deposits is relatively small considering that the volcanic rocks found in this area are types of rocks which have many cracks, fractures, and small cavities which are flanked with groundwater (Iswahyudi et al., 2018).

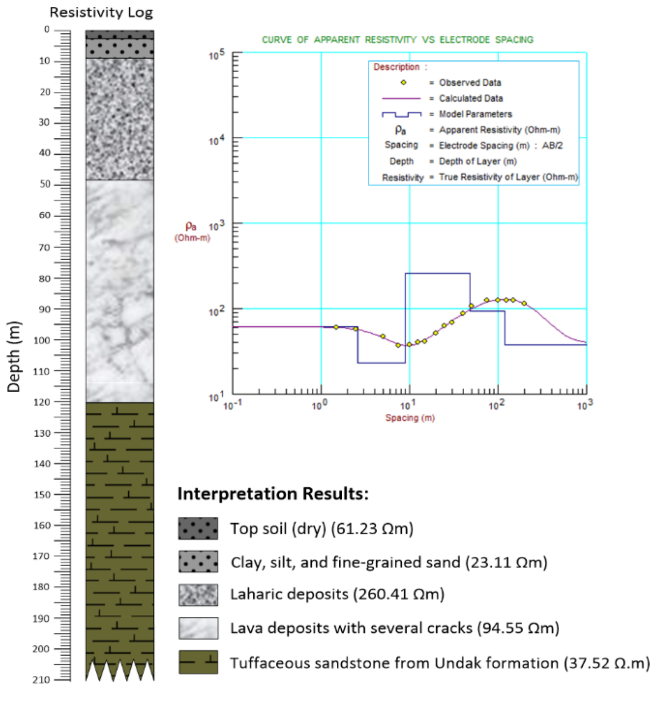

Figure 4: An example of a resistivity curve and rock lithology log for the Sch-1 sounding point.

4.2 Results of Modeling dan Interpretation

Based on the modeling and interpretation results of resistivity data, six subsurface rock layers were obtained. These layers were composed of top soil (0.69 – 61.23 Ωm); interbedded clay, silt and sand (13.05 – 49.14 Ωm), laharic deposits of Slamet Volcano (114.61 – 260.41 Ωm), lava deposits of Slamet Volcano (64.31 – 94.55 Ωm), tuffaceous sandstone (25.59 – 39.14 Ωm), and sand and tuff (8.37 – 20.32 Ωm). This analysis lava rocks in the research area consist of massive lava and vesicular lava (Iswahyudi et al., 2018). Massive lava has a massive layered structure and many cracks and fractures and sometimes forms flow structures. Meanwhile vesicular lava has a hollow structure and regular small cavities. The existence of lava rock with many cracks and small cavities allows groundwater to flow through the rock. These cavities, cracks, and fractures function as a path for groundwater to flow from the recharge area on the southeastern slopes of Slamet Volcano to the groundwater basin discharge area which stretches from Purwokerto City to Purbalingga City. The high rainfall on the recharge area (upper slopes of Slamet Volcano), which reached 8,134 mm per years, then resulted in large groundwater reserves stored in the discharge area (Anonimous, 2024).

Lithology logs at overall sounding points are then correlated to produce a hydrostratigraphic cross-sectional model as shown in Figure 5. Based on the obtaned model, the laharic deposits of Slamet Volcano were interpreted to have a depth ranging from 2.06 – 11.71 m and a thickness of 12.78 – 58.17 m, while the lava rocks had a depth ranging from 3.31 - 69.88 m and a thickness of 37.06 – 72.05 m. The laharic deposits were composed of volcanic rock boulders consisting of andesitic and basaltic with a diameter of 10 – 50 cm so they had less potential to contain groundwater (Djuri et al., 1996). Meanwhile, andesite lava rocks that have many cracks, fractures, and small cavities containing groundwater can be categorized into the fractured aquifers. The modeling results show that under the laharic and andesitic lava deposits there were two rocks of Undak Formation. Based on the geological map of the research area, the formation was composed of several rock layers such as tuffaceous sandstone, conglomerate, tuff, sand, and tuffaceous breccia (Djuri et al., 1996). Hydrogeolog ically, these rock layers can still be occupied and some of them can be traversed by groundwater, so that some of these rocks can still function as aquifers. Groundwater stored in this aquifer has great potential for the development of groundwater-based irrigat ion. Completely results of lithological and hydrogeological interpretation of subsurface rock resistivity data in the research area can be seen in Table 2.

4.3 Analysis and Discussion

Based on the research results shown in Figure 5, the groundwater aquifers in the research area can be divided into three types, i.e. shallow aquifers in the Alluvial Formation, intermediate aquifers in the form of fractured groundwater in the Lava Formation of Slamet Volcano, and deep aquifers interpreted to be found in the Undak Formation. The shallow aquifer found in the research area is an unconfined aquifer, meaning it does not have boundaries as aquitards and aquicludes between the aquifer and the Earth's surface. The modeling and interpretation results such as shown in Figure 5 indicate the presence of shallow aquifers at the sounding points of Sch-1 and Sch-2. Meanwhile, other sounding points do not have the potential for shallow aquifers because the area are located above the lava deposits of Slamet Volcano. The results of study conducted by showed the presence of andesitic lava deposits near the surface of Slamet Volcano with a density of 2.72 g/cm³ (Sehah et al., 2023). The andesitic lava deposits have spread on the topographic surface to the research area, such as shown in Figure 2. Currently, part of the area has been covered by alluvial deposits.

Table 2: Results of lithological and hydrogeological interpretation of subsurface rock resistivity data in the research area

No.	Resistivity (Ωm)	Depth (m)	Lithological Interpretation	Hydrogeological Interpretation
1	0.69 – 61.23	0 – 3.60	Top soil (wet to dry clay)	Non–aquifer
2	13.05 – 49.14	0.87 – 11.71	Interbedded clay, silt, and fine to coarse grained sand	Shallow aquifers
3	114.61 – 260.41	2.06 – 69.88	Laharic deposits are composed of volcanic rock boulders	Non–aquifer
4	64.31 – 94.55	3.31 – 136.90	Andesitic lava rocks with cracks, fractures, and small cavities flanked by groundwater	Fractured aquifers
5	25.59 – 39.14	> 51.90	Tuffaceous sandstone from the Undak formation	Aquitard
6	8,37 – 20,32	> 120.12	Sand and tuffs from the Undak formation	Deep aquifers

Geological information shows that the andesitic lava rocks in this area have many fractures and cracks, that allow groundwater to flow through the rock, thus forming a fractured aquifer (Iswahyudi et al., 2018). A fractured aquifer is a rock formation that contains enough cracks, fractures, local faults, and fissures to provide economical amounts of water to springs (Zhou et al., 2023). The fractured groundwater in the research area is estimated to be found in the andesitic lava rocks. Figure 5 shows that the depth of the andesitic lava deposits interpreted as fractured aquifers ranges from 3.31 – 136.90 m from the topographic, while the layer thickness ranges from 12.78 – 71.10 m. Several images of andesitic lava rock outcrops with many cracks found in the northeast of the research area are also shown in Figure 5. In the rocks, a fracture can sometimes form a deep, wide crack in the rock. They are usually caused when the rock is not strong enough to hold up under too much stress. Fractures found in the rocks form in response to stress. Specifically, the rock breaks and forms a fracture when the applied stress has reached a certain limit, i.e. the rock strength. The stress associated with the fracture formation may be normal or shear or both (Gudmundsson, 2011). Geolo gical stress refers to the force exerted on rock formations within the Earth's crust, resulting in deformation and affecting structures such as faults and folds. The stresses which occur in the research area may come from three types, that are compression (pushing rocks together), tension (pulling rocks apart), and shear (sliding past each other), each of that affects the condition of rocks on the surface differently. Apart from that, the formation of fractured aquifers is also influenced by weathering and different phases of lava flow formation, thus forming different layers around the slopes of Slamet Volcano (Iswahyudi et al., 2018). The weathering process in rocks can occur due to physical and chemical reactions between rocks and the interaction of air, water and certain organisms. After rocks become weathered, they become sedimentary material through the process of erosion, which makes it easier for groundwater to enter them.

The research area has fractured groundwater that can be used as a source of irrigation water for the surrounding agricultural land. Water is a crucial element for the farming sector, ensuring that there is a consistent water supply is essential for the successful growth of agrarian crops throughout the year. Meanwhile surface water from rivers, reservoirs, and lakes has traditionally been used for irrigation, there is often a shortage of water during the dry season, causes drought in plants. Considering these challenges, it is important to explore alternative water sources to meet the needs of plants. Groundwater is one of promising option for agricultural irrigation, especially in areas with groundwater fractures such as the research area. Developing fractured groundwater resources for irrigation requires more complex infrastructure than shallow groundwater. This includes conducting geoelectric surveys, drilling in lava rock formations to access fractured aquifers, and building water pump installations and reservoirs for water distribution. In addition to irrigation, fractured groundwater is also used for household and industrial purposes. Moreover, the discharge area of the Purwokerto-Purbalingga Groundwater Basin area has rapidly developed into an urban area dominated by settlement and industrial areas (Ramadhan, 2020).

5. Conclusion

Resistivity survey using VES technique has been carried out at five sounding points in the Padamara District area, Purbalingga Regency Indonesia. The purposes of the research was to obtain the data on the depth and thickness of the Lava Formation in the research area that acts as a fractured groundwater aquifers. The obtained results of data processing were resistivity data for each subsurface rock layer at five sounding points with values ranging from 0.69 – 260.41 Ωm. Furthermore, interpretation of resistivity data has resulted lithological logs and correlation between lithological logs has resulted a hydrostratigraphic cross-sectional model. Based on the model, the stratigraphy of the research area was composed of top soil with a resistivity value of 0.69 – 61.23 Ωm; interbedded clay, silt, sand with a resistivity value of 13.05 – 49.14 Ωm; laharic deposits with a resistivity value of 114.69 – 260.41 Ωm; lava deposits with a resistivity value of 64.31 – 94.55 Ωm; tuffaceous sandstone with a resistivity value of 25.59 – 39.14 Ωm; and sand and tuff with a resistivity value of 8.37 – 20.32 Ωm. The aquifers in the research area could be classified into three types, that are shallow aquifers in the Alluvium Formation, intermediate aquifers in the form of fractured aquifers in the Lava Formation, and deep aquifers in the Undak Formation. The depth of lava rocks which had the potential to act as fractured groundwater ranges from 3.31 – 136.90 m from the topographical surface, whereas the thickness ranges from 12.78 – 71.10 m.

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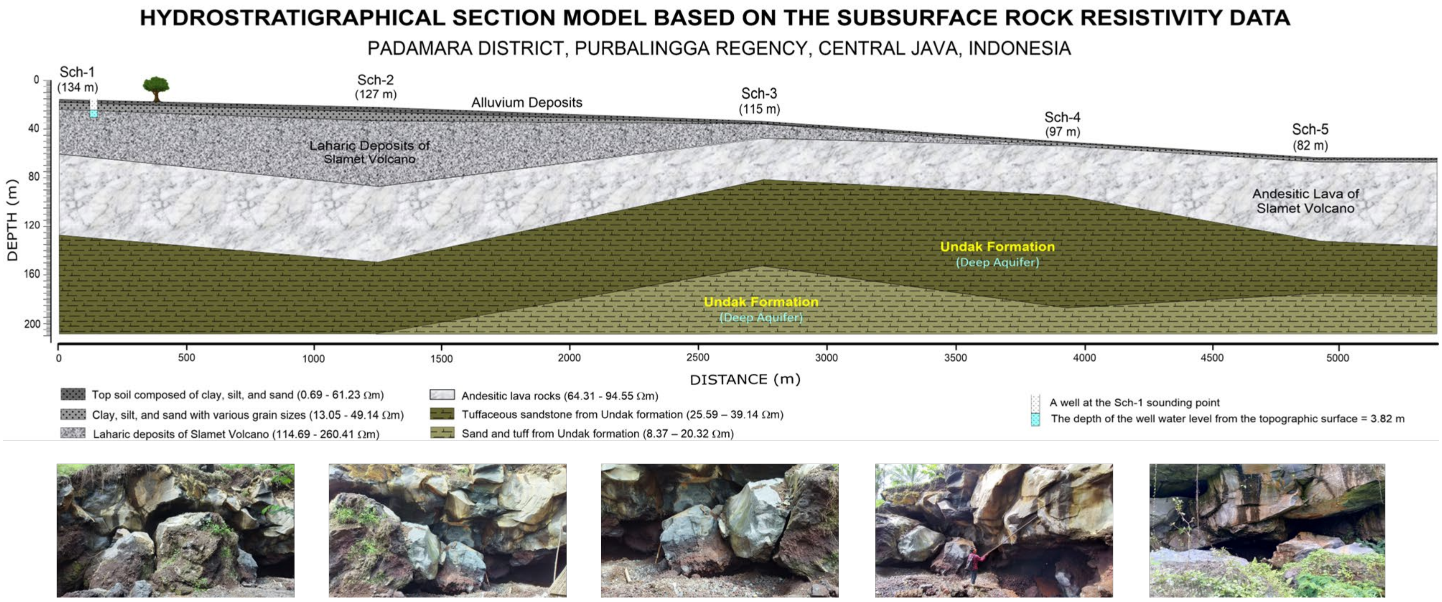

Figure 5: Hydrostratigraphic cross-section model based on subsurface rock resistivity data in the research area and several images of andesitic lava rock outcrops with many cracks found in the northeast of the research area.

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