HYDROSTRATIGRAPHIC MODELING OF THE PURWOKERTO-PURBALINGGA GROUNDWATER BASIN BASED ON GRAVITY AND RESISTIVITY DATA IN KALIMANAH DISTRICT, PURBALINGGA REGENCY

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Abstract. The utilization of gravimetric satellite data for mapping gravity anomalies on the Earth's surface has been carried out in the Purwokerto-Purbalingga Groundwater Basin area. The research has produced a 3D subsurface rock density model with values ranging from 1.20 – 4.80 g/cm^3. The inversion modeling results showed that the shape of the discharge area of Purwokerto-Purbalingga Groundwater Basin resembled a bowl filled with alluvial sediment with density values ranging from 2.10 – 2.55 g/cm^3 and a depth of more than 4 km. The results were justified using resistivity data, one of which was carried out in Kalimanah District, Purbalingga Regency. The aim of this research was to obtain a hydrostratigraphic model based on resistivity data so the aquifer layers can be easily identified. The obtained results were subsurface rock resistivity logs which spread across five sounding points with resistivity values ranging from 1.31 – 110.88 Ωm. These sounding points were located at geographical positions 7°24'24.93" and 109°19'13.58" to 7°24'23.28" and 109°21'10.29". The interpretation of resistivity logs has produced lithological logs at each point. Correlation of all lithology logs has resulted a hydrostratigraphic model of the research area consisting of five layers, which are topsoil (1.31 – 18.38 Ωm); clay, silt, and sand (9.27 – 110.88 Ωm); sand with variations in grain size (13.0 5 – 64.31 Ωm); tuffaceous sandstone and breccia (28.32 – 77.28 Ωm); as well as sand, tuff, and conglomerate (11.72 – 20.32 Ωm). The second, third, and fifth layers are interpreted as the most potential aquifer layers.

Keywords: hydrostratigraphic model, Purwokerto-Purbalingga Basin, satellite gravity data, resistivity data

A. Introduction

Groundwater is one of the links in the hydrological cycle on Earth. Groundwater comes from rainwater which seeps into the soil and rocks through pores and cracks in the recharge areas which generally have high topography. Groundwater flows and is stored in small open spaces between rocks, sand, soil, and gravel below the surface called aquifers, which are generally located in the discharge areas in a groundwater basin. A groundwater basin can be defined as an area bounded by hydrogeological boundaries, where all hydrogeological events such as recharge, drainage and release of groundwater take place [1]. Groundwater plays an important role in maintaining the balance and availability of water for households, agriculture, livestock, and industry. One of the groundwater basins in Indonesia that needs further study for wider use is the Purwokerto-Purbalingga Groundwater Basin. This basin is one of the largest groundwater basins in Central Java with an area of around 1,318 km^2 [2] which is estimated to contain large amounts of groundwater. The information and data obtained from this study are very useful to support the development of groundwater-based agricultural irrigation, especially in the Central Java Province, Indonesia.

The gravimetric satellite data has been utilized to analyze the potential of the Purwokerto-Purbalingga Groundwater Basin as a source of irrigation. The data used is GGM plus gravity anomaly data with a total of 51,900 data, which stretches at geographic positions 109.0083° – 109.6083° E and 7.2554° – 7.6026° S. After going through the processing and modeling stages of gravity anomaly data, a subsurface rock density distribution model was obtained with values ranging from 1.20 – 4.80 g/cm^3 [3]. Based on the obtained model, then the basin area which is estimated to contain large amounts of groundwater is interpreted to be composed of alluvial deposits with density values ranging from 2.10 – 2.55 g/cm^3 and a depth of more than 4 km [3]. This basin forms a collective saturated space containing various materials such as sand, silt, and gravel which are connected to form an integrated aquifer system [4]. One of the cross-sections of the integrated aquifer from the model obtained is shown in Figure 1. The results of this study provide an important stage in the development of the Purwokerto-Purbalingga Groundwater Basin as a potential freshwater source for sustainable agricultural irrigation. Therefore, further exploration of deep groundwater aquifers using geoelectric surveys in several locations which are estimated to have great potential based on the results of interpretation of satellite gravity anomaly data is needed.

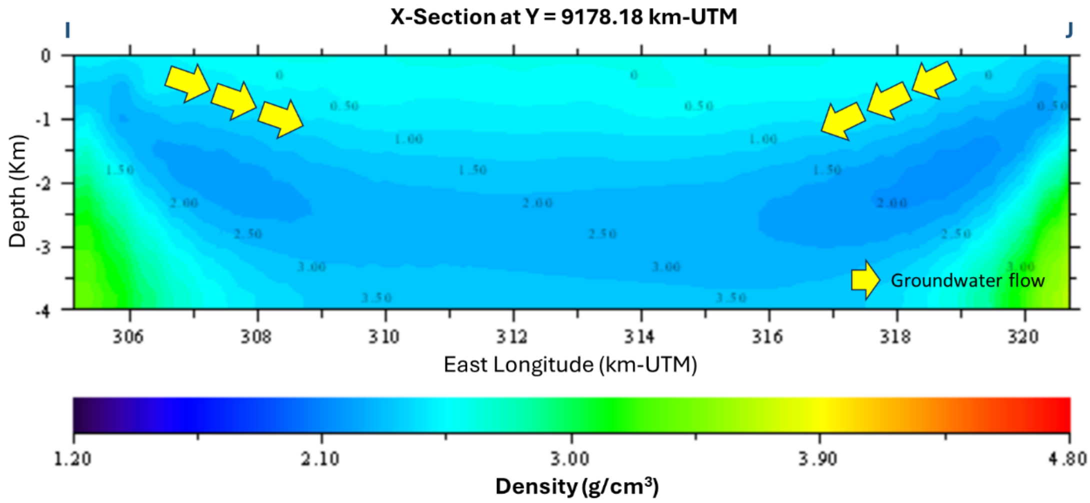

Figure 1. Cross-section of the results of the subsurface structure model of the Purwokerto-Purbalingga Groundwater Basin area along the latitude 9178.18 km-UTM.

Geoelctric-resistivity survey is a method in geophysics to determine the different resistivity values of varying subsurface to confirm the presence of groundwater or subsubsurface rocks in an area. The resistivity method has been applied to identify the characteristics of the aquifer in the Lake Maninjau area, Sumatra Island [5]. This method was also successfully used to detect the presence of aquifer layers in the ITO Campus area, Kyushu University, Fukuoka, Japan [6]. The author also succeeded in using the resistivity method to obtain a hydrostratigraphic model of the Serayu River bank area in Sokawera Village, Somagede District, Banyumas Regency, Central Java [7]. Apart from that, the author also succeeded in applying the same method to detect the depth of the aquifer and compared the results with the results of well drilling in Jatilawang District, Banyumas Regency, Central Java, Indonesia [8]. Detection of groundwater depth using the resistivity method has been tested with an accuracy of up to 80% [9], hence this method is suitable for supporting research results using satellite gravity anomaly data. Hence, the subsurface rock density model for the Purwokerto-Purbalingga Groundwater Basin area that covers a large area with a depth of more than 4 km needs to be detailed through a geoelectric-resistivity survey.

One of the areas located in the groundwater discharge area of the Purwokerto-Purbalingga Basin is Kalimanah District, Purbalingga Regency. Geologically, the research area is located in the Alluvium Formation which is composed of gravel, sand, silt, and clay from river and coastal deposits [10], and volcanic material in the form of non-hardened materials, which are composed of andesitic to basaltic with low to high water flow gradations [11]. The northern part of the research area is bordered by laharic deposits and vesicular andesite lava from the Slamet Volcano with high to moderate water flows. Below the Alluvium and volcanic rock formations there is the Undak Formation that is composed of layers of tuffaceous sandstone, sand, tuff, conglomerate, and tuffaceous breccia [10] with low groundwater flow gradation. Therefore, the research target is to obtain a hydrostratigraphic cross-sectional model in the research area that describes the distribution model and depth of the groundwater aquifer layers, especially those with prospects for exploitation. The study results contribute to planning the use of groundwater in the Purwokerto-Purbalingga Basin area for drinking water, industry, fisheries, livestock, agricultural irrigation, and various other sectors on a sustainable basis.

B. Methods

1. Location and Time

Resistivity data acquisition in this survey was carried out in Kalimanah District Purbalingga Regency Central Java. Hydrologically, the study area was included in the groundwater discharge area of the Purwokerto-Purbalingga Basin as shown in Figure 2. The number of sounding points for which resistivity data has been measured is 5 points with geographical positions as explained in the Introduction section. Resistivity data processing and modeling have been carried out in the Electronics, Instrumentation and Geophysics Laboratory; Faculty of Mathematics and Natural Sciences, Jenderal Soedirman University, Purwokerto, Indonesia. This research was carried out for 8 months, i.e. March – October 2024.

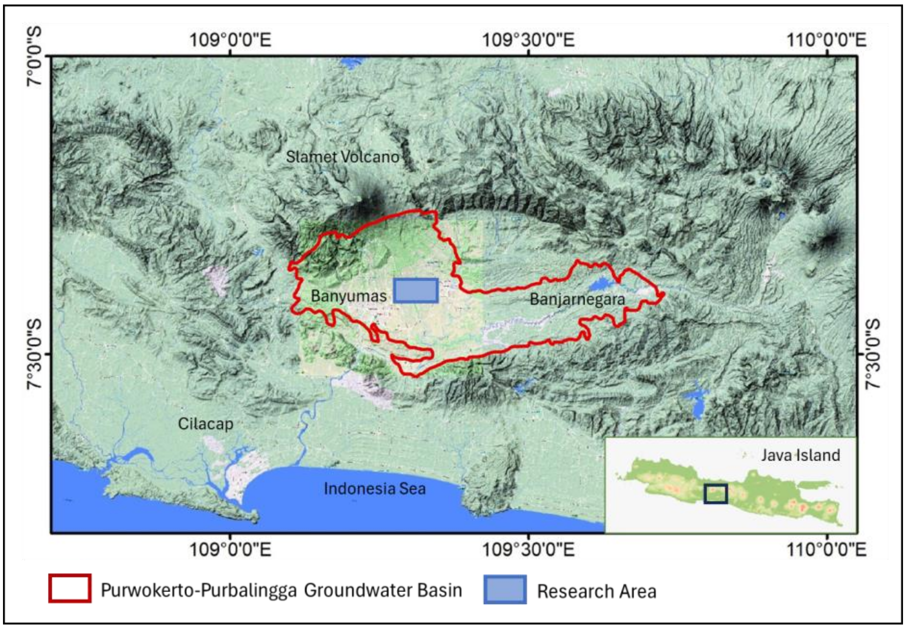

Figure 2. The research location map; the Purwokerto-Purbalingga Groundwater Basin area of Central Java, Indonesia (source: Google Earth).

2. Research Equipments

The main equipment used in the research was a Naniura NRD-300 resistivitymeter which was used to measure rock resistivity data at all location points. This research equipment was equipped with 2 stainless steel electrodes for electrical current, 2 copper electrodes for voltage, 12V-battery, 2 potential cables with a length of 500 m, 2 current cables with a length of 500 m, and 4 rolling meters. Other supporting equipment was a hammer, connectors, connecting cables, and Global Positioning System (GPS). Furthermore, application programs and software used in processing resistivity data include Microsoft Excel 2010, Progress 3.0, and Surfer 17. Progress 3.0 was used to model resistivity data so that the resistivity logs were obtained at each sounding point, while the Surfer 17 was used to create lithological logs based on interpretation results of resistivity data, and correlation between lithological logs so that a hydrostratigraphical model of the research area can be formed [7].

3. Research Procedure

The geoelectric method commonly applied for the exploration of groundwater sources in the subsurface is the resistivity method using the Vertical Electrical Sounding (VES) technique. This technique generally uses a Schlumberger electrode configuration. The resistivity data acquisition technique was carried out by flowing direct electric current into the Earth's surface through two current electrodes at points C_1 and C_2. Electric current injected into the Earth spread evenly through the rock medium. Further, the electric polarization in the rock medium was measured by the potential difference through two potential electrodes at points P1 and P2. This technique was applied in this research because it had the advantage that the penetration depth was relatively deep, making it suitable for interpreting subsurface geological structures, especially groundwater aquifers [12]. According to Reynolds [13], the apparent resistivity value measured during data acquisition can be expressed as:

$$\rho_a = K\frac{\Delta V}{I} \qquad (1)$$

where ρ_a is the apparent resistivity (Ωm), ΔV is the potential difference or electrical voltage (volt), I is the electrical current flowing through the rock medium (A), and K is the geometry factor of the electrode configuration used. For the Schlumberger configuration, the geometric factor value can be expressed by the equation [13]:

$$K = \pi\left(\frac{a^2 - b^2}{2b}\right) \qquad (2)$$

where a is the distance of ½C_1C_2 and b is the distance of P_1P_2 as shown in Figure 3.

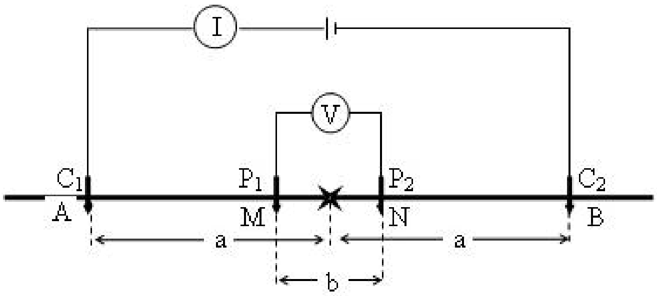

Figure 3. The Schlumberger electrode configuration in resistivity data acquisition.

Data acquisition in geoelectric-resistivity surveys using the VES technique which is carried out by changing the distance of the current and potential electrodes from the smallest distance, then increasing the width gradually as shown in Figure 4. This variation in electrode distance was carried out to obtain subsurface lithology information based on vertical subsurface rock resistivity data. The increase in the current electrode distance was proportional to the increase in the depth of the subsurface rock layers obtained. This means that the greater the distance between the current electrodes, the deeper the subsurface rock layer was detected [14]. The result of the resistivity data acquisition using the VES technique was an apparent resistivity curve (ρ_a) versus half current electrode spacing. The apparent resistivity curve was used as the basis for calculating the true resistivity value (ρ_T) of the subsurface rock layers by modeling. The results obtained were the true resistivity curve versus the half-current electrode spacing and the resistivity log versus the depth of each rock layer. The interpretation was carried out on the resistivity log data based on the geological information of the research area to obtain a lithological log that showed the various subsurface rock layers and their depths. The correlation performed on lithological logs can be carried out to describe the hydrostratigraphic model of the study area including the groundwater aquifer which has the prospect of being exploited [7].

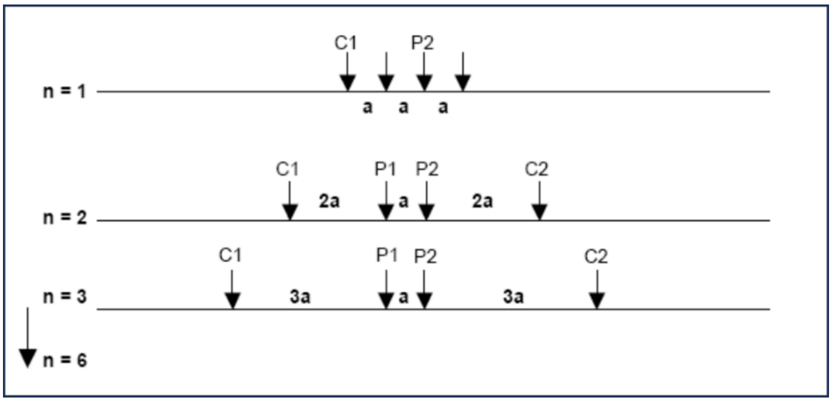

Figure 4. Changes in current and potential electrode spacing during resistivity data acquisition using the Schlumberger configuration.

C. Results And Discussion

1. Resistivity Data Modeling and Interpretation Results

Resistivity data acquisition was carried out at 5 sounding points in the research area with geographical positions as shown in Table 1. The obtained data were current (I), voltage (ΔV), and distance between electrodes. These data were processed further, so that the geometric factor (K) and apparent resistivity (ρ_a) values were obtained for each measurement [15]. The apparent resistivity data was successfully modeled using Progress 3.0 to obtain the true resistivity data. The resistivity log is interpreted based on the geological information to obtain a lithological log which shows the stratigraphic sequence of subsurface rocks in the local area. The resistivity curve and lithological log of subsurface rocks at points Sch-1 to Sch-5 are shown in Figure 5 to Figure 9. The results of the lithological interpretation showed that the subsurface rocks found in the research area through a resistivity survey with a current electrode stretch length of 400 m were the Alluvium and Undak formations. The Alluvium Formation was found at all sounding points below the topsoil at depths varying from 1.26 – 5.06 m, while the Undak Formation was found at depths ranging from 44.84 – 74.73 m from the topography surface. The Alluvium Formation is interpreted to fill the subsurface rock layers that include the first, second, and third layers. Meanwhile, the Undak Formation is interpreted to fill the fourth and fifth rock layers.

Modeling and interpretation results showed that the Alluvium Formation was composed of three subsurface rock layers which included topsoil (1.31 – 18.38 Ωm); interbedded clay, silt, and sand (9.27 – 110.88 Ωm); as well as sand with varying grain sizes (13.05 – 64.31 Ωm). Meanwhile, the Undak Formation was composed of sandstone and tuff breccia (28.32 – 77.28 Ωm) as well as interbedded sandstone, tuff, and conglomerate (11.72 – 20.32 Ωm). Analysis of these rock layers showed that the most potential aquifer was thought to be found in the second and third subsurface rock layers of the Alluvium Formation. The aquifer layer was composed of a collection of unconsolidated rocks or sediment which had sufficient porosity and permeability to allow groundwater to flow through them. Unconsolidated materials such as gravel, sand, and even silt make relatively good aquifers. Different kinds of soil and rock vary in the size of the spaces for water to move through. It is easier for water to move through bigger spaces. Gravel and sand have very large spaces, so water moves through them very fast. On the other hand, the spaces in clay are so small that almost no water moves through. Geology plays an important role in the amount of water stored and flowing within rock layers. If the pores in the rock are large and connected, groundwater will flow faster than if they were small, isolated holes [16].

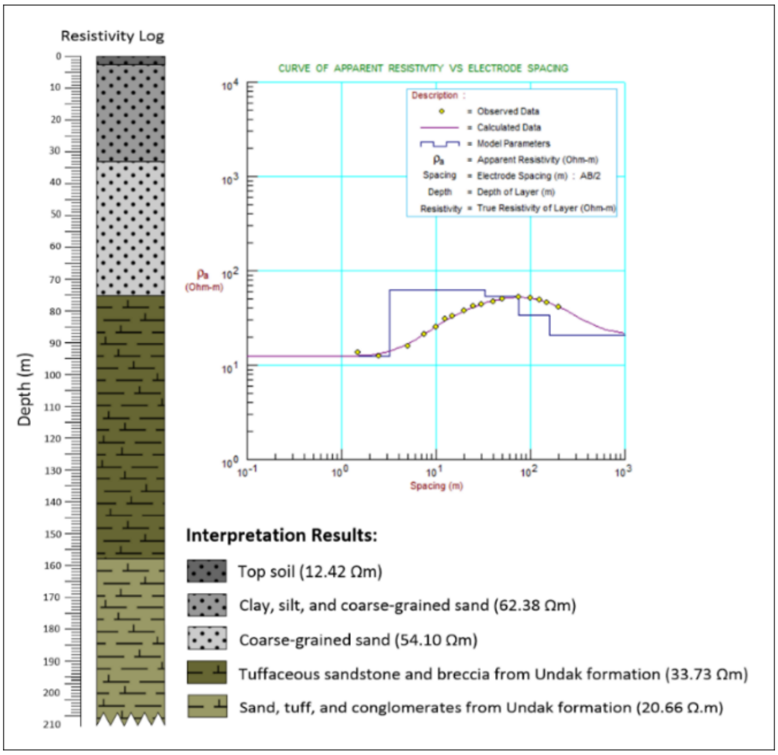

Figure 5. Lithological log and resistivity curve at the Sch-1 sounding point.

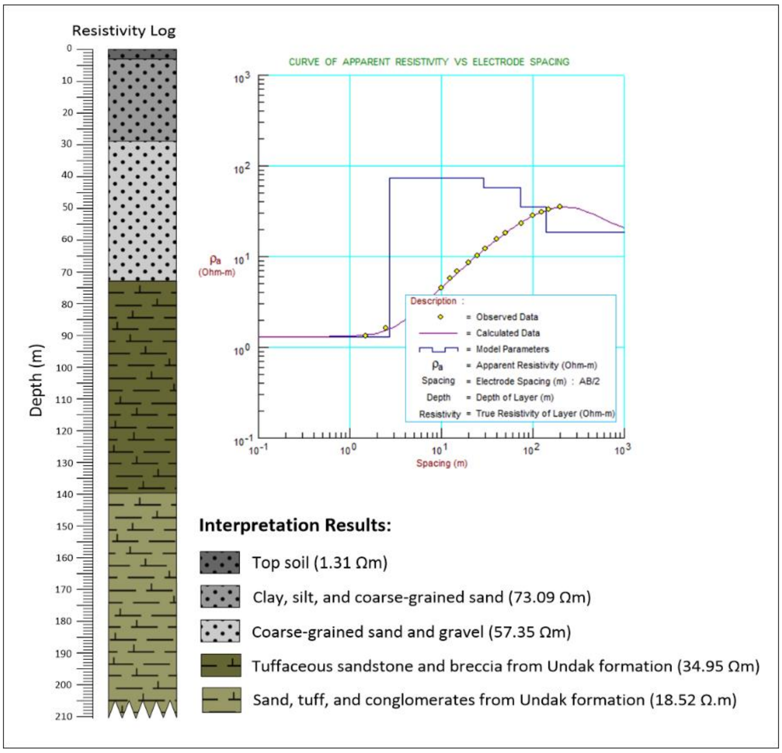

Figure 6. Lithological log and resistivity curve at the Sch-2 sounding point.

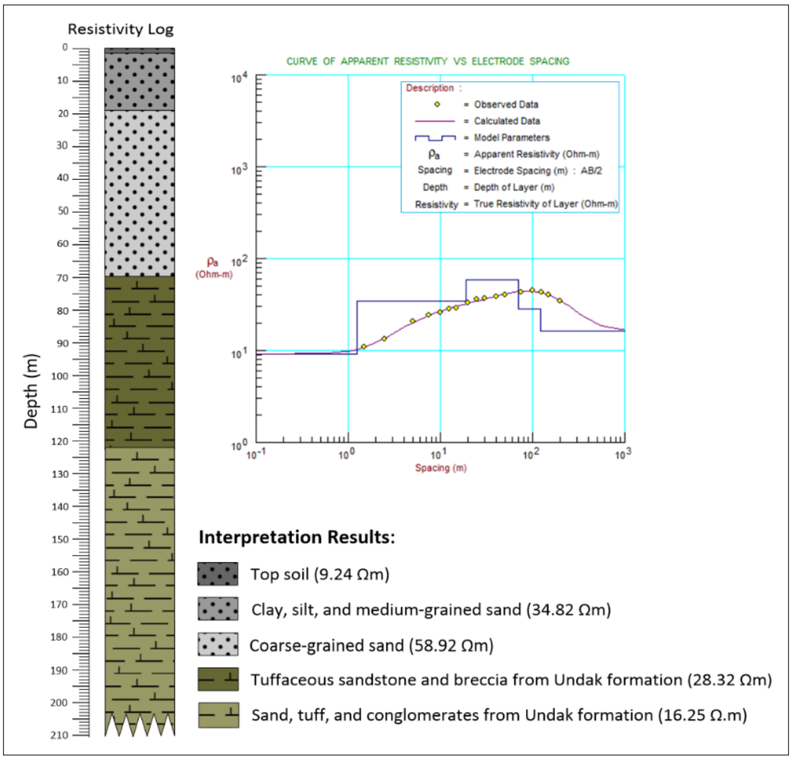

Figure 7. Lithological log and resistivity curve at the Sch-3 sounding point.

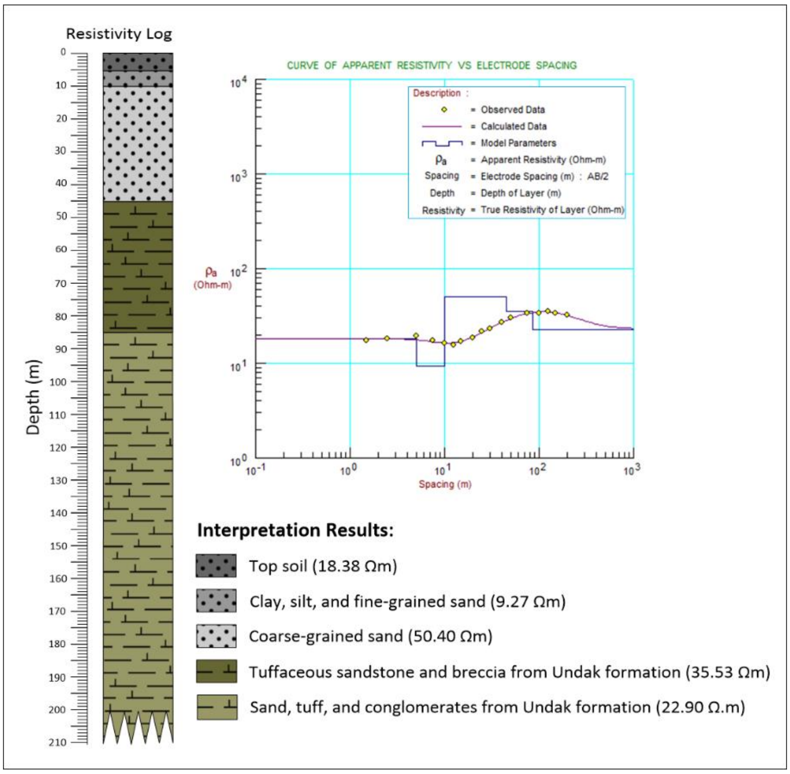

Figure 8. Lithological log and resistivity curve at the Sch-4 sounding point.

Correlation between subsurface rock lithology logs has produced a hydrostratigraphic cross-section model of the study area as can be seen in Figure 8. Based on the model, the Alluvium Formation was estimated to have a depth ranging from 1.26 – 74.73 m. Meanwhile the Undak Formation was estimated to be found at a depth of more than 44.84 m. Alluvium Formation rocks that had high porosity and permeability generally functioned effectively as aquifer layers and also as potential groundwater sources. Meanwhile, the Undak Formation was composed of several rocks such as tuff, sand, conglomerate, and tuffaceous sandstone, and tuffaceous breccia with varying porosity and permeability from low to high. Changes in porosity and permeability in the Undak Formation deposits were due to compaction, cementation, and changes in pore connectivity during diagenesis and consolidation processes [17]. Hydrogeologically, the rock formation layers can still accommodate and drain groundwater at moderate to good levels. The fourth rock layer is interpreted to be composed of tuffaceous sandstone and breccia which does not act well as an aquifer. Meanwhile the fifth layer which is interpreted to be composed of sand, tuff, and conglomerate allows water to flow within it, especially through sand pores, so it can be called a deep aquifer. This deep groundwater aquifer is estimated to have a high potential to be utilized in the development of groundwater-based irrigation [18].

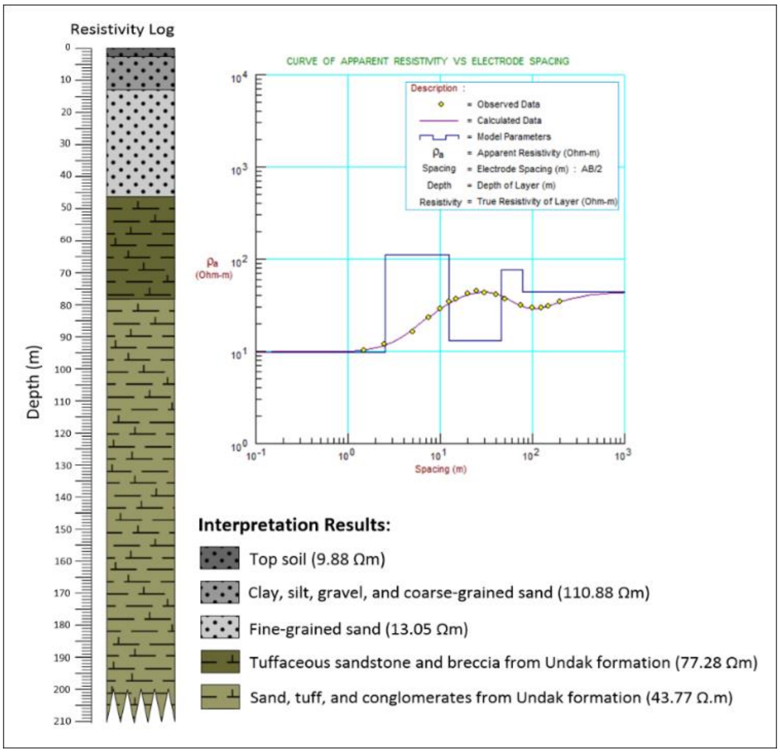

Figure 9. Lithological log and rock resistivity curve at the Sch-5 sounding point.

Based on the modeling and interpretation results of resistivity data, the groundwater aquifer in the research area can be grouped into three types, i.e. shallow aquifers that are composed of clay, silt, and sand with various grain sizes; intermediate aquifers that are composed of fine to coarse-grained sand; and the deep aquifer that is composed of sand, tuff and conglomerate from the Undak Formation. In more detail, the lithological and hydrogeological interpretation results of resistivity data in the research area can be seen in Table 1. The source of groundwater for the shallow and intermediate aquifer layers generally comes from surface water, such as rainwater and river water which infiltrates into the soil and rocks. Meanwhile, groundwater sources for deep aquifers generally come from recharge areas such as the Slamet Volcano slopes and the North Serayu Mountains [2]. Groundwater is obtained from the rainwater deposition process and accumulates in cavities and rock cracks, then flows to discharge areas at lower elevations. Rainfall in the recharge area can reach 2,800 mm per year, while in the discharge area, it is only 1,200 mm per year [2].

Table 1. Interpretation results of lithological and hydrogeological data from subsurface rock resistivity in the research area

No.	Resistivity (Ωm)	Depth (m)	Interpretation	
			Lithology	Hydrogeology
1	1.31 – 18.38	0 – 5.06	Top soil is dominated by clay	Non-aquifer
2	9.27 – 110.88	1.26 – 5.06	Clay, silt, and sand with varying grain sizes from Alluvium Formation	Shallow aquifer
3	13.05 – 64.31	9.96 – 32.91	Sand with varying grain sizes from Alluvium Formation	Intermediate aquifer
4	28.32 – 77.28	44.84 – 74.73	Tuffaceous sandstone and breccia from Undak Formation	Aquitard
5	11.72 – 48.77	> 77.99	Sand, tuff, and conglomerate from Undak Formation	Deep aquifer

2. Analysis and Discussion

The community has long been using surface water for irrigation in the Purbalingga Regency area. However, since the need for irrigation water is not proportional to the area of agricultural land, often some plants cultivated during certain periods experience drought, especially during the dry season. Based on these facts, it is necessary to explore alternative solutions to meet the irrigation water needs for plants. Groundwater is one of the freshwater source options that can be developed for sustainable agricultural irrigation. The results of the research in the form of a hydrostratigraphic cross-sectional model based on resistivity data as shown in Figure 10 can be utilized as supporting data in exploring groundwater sources for irrigation development in the Purbalingga Regency and surrounding areas. Based on the hydrostratigraphical model, the research area has the potential for shallow, intermediate, and deep groundwater sources. Shallow groundwater is generally used for domestic needs or daily household needs [19] so that agricultural land irrigation is more focused on utilizing intermediate and deep groundwater. Several wells in Kedungwuluh and Kalikabong villages, Kalimanah District which originate from shallow aquifers are shown in Figure 11. The water source of these wells is found at a depth of 5 – 7 m from the topographical surface, but the depth of the groundwater level is only around 1 – 2 m.

The presence of deep groundwater in this area is influenced by the amount of rainfall and water that seeps into the ground [20], especially in the recharge area on the southern and eastern slopes of Slamet Volcano. Slamet Volcano has the widest diameter in Indonesia with a vegetation area of around 312 km² or 31,200 hectares and a mountain area of 560 km² or 56,000 hectares. This area is one of the areas with the highest annual rainfall in Indonesia, i.e. 8,134.00 mm per year with the coldest average temperature on Java Island [21]. Rainwater is the main source of groundwater, apart from other water sources. The amount of rainwater that seeps into soil and rocks is influenced by the porosity and permeability of rocks; geology, lithology, and topography conditions; as well as land use and cover [22]. With very high rainfall, the volume of groundwater from the recharge area flowing into the Purwokerto-Purbalingga Groundwater Basin becomes very large. Groundwater reserves in the deep aquifer layer have the potential to be used to develop agricultural irrigation. Rice fields that receive irrigation water from the surface or are rain-fed generally still have low levels of productivity and planting intensity. However, the potential for land resources and opportunities to increase production are still quite large. Therefore, increasing productivity, intensity, and diversity of food plants on rice fields in Kalimanah District, Purbalingga Regency, Central Java can be realized through a groundwater-based irrigation system.

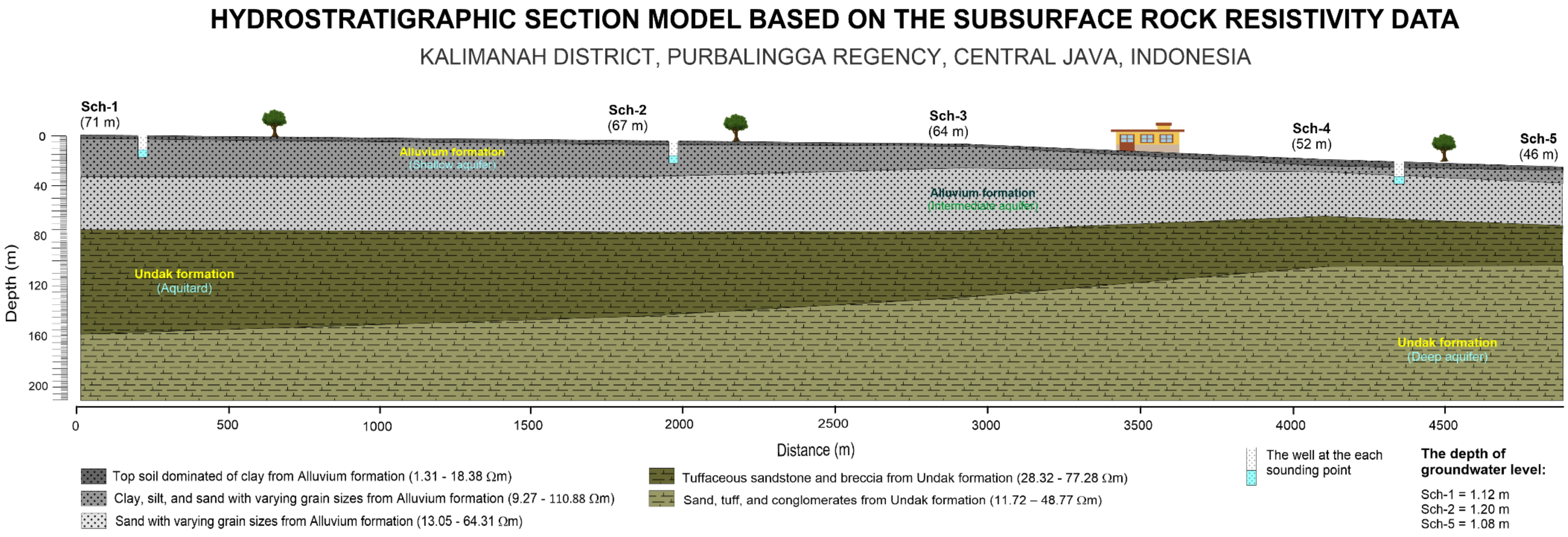

Figure 10. Hydrostratigraphic cross-section model based on subsurface rock resistivity data in the research area.

Figure 11. Several resident's wells sourced from shallow aquifers in Kalimanah District, Purbalingga Regency.

D. Conclusion

The use of gravimetric satellite data to map gravity anomaly data has been carried out in the Purwokerto-Purbalingga Groundwater Basin area. The research produced a three-dimensional subsurface model with density values ranging from 1.20 – 4.80 g/cm^3. The results of inversion modeling showed that the groundwater discharge area was a basin containing alluvial deposits with density values ranging from 2.10 – 2.55 g/cm^3 and a depth of more than 4 km. The research results had been justified using resistivity surveys, one of which was carried out in Kalimanah District, Purbalingga Regency. The purpose of this research was to obtain a hydrostratigraphic sectional model based on resistivity data so that groundwater aquifer layers can be identified. The obtained resistivity acquisition results were subsurface rock resistivity logs at five sounding points with resistivity values ranging from 1.31 – 110.88 Ωm. The data points were distributed over positions of 7°24′24.93″ S and 109°19′13.58″ E to 7°24′23.28″ S and 109°21′10.29″ E. Interpretation of the resistivity log has been carried out so that a lithological log is produced at each sounding point. The correlation of all lithological logs has produced a hydrostratigraphic cross-sectional model of the research area which consists of five rock layers. These layers were composed of topsoil (1.31 – 18.38 Ωm); clay, silt, and sand (9.27 – 110.88 Ωm); sand varying grain size (13.05 – 64.31 Ωm); tuffaceous sandstone and breccia (28.32 – 77.28 Ωm); and sandstone, tuff, and conglomerate (11.72 – 20.32 Ωm). Analysis of the rock layers shows that groundwater that has the potential to be exploited is estimated to be found in the second and third layers of the Alluvial Formation which act as shallow and medium aquifers, as well as the fifth layer of the Undak Formation which acts as a deep aquifer.

E. Acknowledgement

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